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THE ROYAL AERONAUTICAL SOCIETY

OCTOBER 1961

CONTENTS

NOTICES

THE ERA OF THE AUTOGIRO—THE FIRST CIERVA MEMORIAL LECTURE — J. A J. BENNETT

RECENT DEVELOPMENTS IN PHOTOELASTIC COATING TECHNIQUES — G. S. HOLISTER

SPACE-CORRELATIONS IN THE FLUCTUATING PRESSURE FIELD NEAR TO A JET ENGINE — R. E. FRANKLIN

SOME THRUST CONTROL METHODS FOR SOLID PROPELLANT ROCKETS — K. W. PEARCE

TECHNICAL NOTES

The Application of the Schlieren-Interferometer to the Study of Supersonic Flow Around Unyawed Axi-Symmetric Bodies—J. F. WATERHOUSE and H. B. SPENCER. Vibration of Centrally Stiffened Rectangular Plate —C. L. KIRK.

THE ROYAL AERONAUTICAL SOCIETY: THE FIRST FIFTY YEARS—1875-6 — J. LAURENCE PRITCHARD

GRADUATES' AND STUDENTS' SECTION

THE BRANCHES

THE LIBRARY REVIEWS REPORTS

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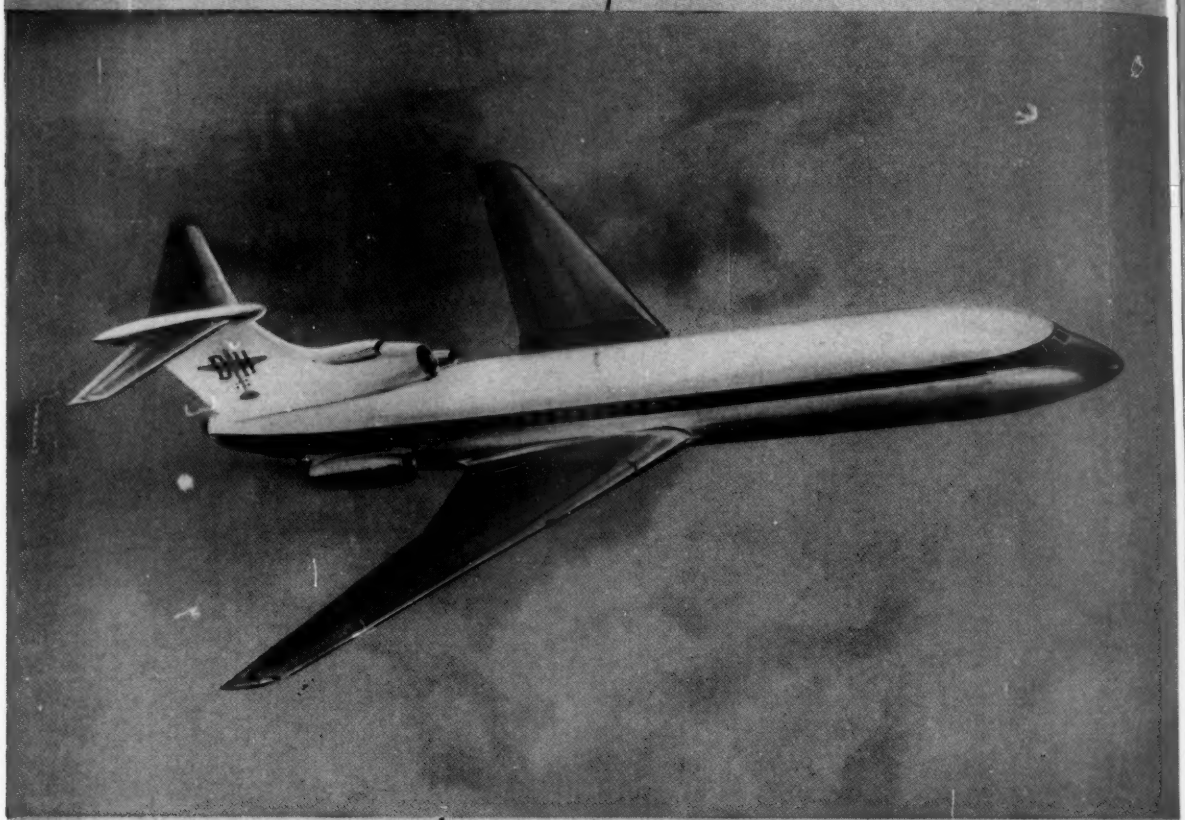

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VOLUME 65 OCTOBER 1961 NUMBER 610

CONTENTS

PAGE

Notices XLI

Eighth Anglo-American Aeronautical Conference: Paper by Dr. G. E. Mueller—Historic Aircraft Maintenance: an Appeal—Fifth Lanchester Memorial Lecture—Seventeenth British Commonwealth Lecture—Second Rocket Propulsion Symposium—International Flight Test Instrumentation Symposium—Overseas Visitors—Conference on International Developments in Heat Transfer—Acknowledgment—Second Annual Rotorcraft Dinner—Diary—News of Members—Zonta Amelia Earhart Scholarships—Supplement to the Oxford English Dictionary—Lecture Summaries.

The Era of the Autogiro—The First Cierva Memorial Lecture — J. A. J. BENNETT — 649

Recent Developments in Photoelastic Coating Techniques — G. S. HOLISTER — 661

Space-Correlations in the Fluctuating Pressure Field Near to a Jet Engine — R. E. FRANKLIN — 670

Some Thrust Control Methods for Solid Propellant Rockets — K. W. PEARCE — 677

Technical Notes 691

The Application of the Schlieren—Interferometer to the Study of Supersonic Flow Around Unyawed Axi-Symmetric Bodies—J. F. WATERHOUSE and H. B. SPENCER. Vibration of Centrally Stiffened Rectangular Plate—C. L. KIRK.

The Royal Aeronautical Society: The First Fifty Years—1875-6 — J. LAURENCE PRITCHARD — 698

Graduates' and Students' Section 701

The Branches 702

The Library 703

REVIEWS: Encyclopaedic Dictionary of Physics—Modern Flight Dynamics—The Modern Airliner—Die Berechnung von Rotierenden Scheiben und Schalen — Rumpf Schalen: und Vollwand Bauweise — Die Deutschen Flugzeuge 1933-1945.

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None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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NOTICES

Eighth Anglo-American Aeronautical Conference—Paper by Dr. George E. Mueller

Among the advance copies of the Conference papers received by delegates was one entitled "Communications Satellites" by Dr. George E. Mueller, W. B. Hebenstreit and E. R. Spangler, but a different paper, "Advancement in Spacecraft Technology" by Dr. Mueller alone, was read on his behalf at the Conference and will be published in the final Proceedings.

The paper "Communications Satellites," was sent to the Society early in August in error; this error was not made known to the Society until four days before the lecture was due to be given. This paper is in fact the copyright of the British Interplanetary Society and is to be published by them as part of a Proceedings.

Historic Aircraft Maintenance—An Appeal

The Historic Aircraft Maintenance Group are scheduling work on the Nash Collection of Veteran Aircraft at London Airport for the Winter months of 1961-1962. There are several vacancies for volunteers in the following capacities:

Experienced woodworkers for the repair and manufacture of aircraft components.
Engine fitters for overhauling aero engines.
Research on points of technical and historical accuracy.

Anyone interested should get in touch with Mr. A. S. Hughes, Chief Engineer, Historic Aircraft Maintenance Group, at 131 Clare Road, Stanwell, Staines, Middlesex, or by telephone at Skyport 5511. Extn. 3498.

Overseas Visitors

Among the many visitors who called on the Secretary during the past month was Professor S. Smoleniec, President of the Southern African Division, when matters of mutual interest to the Division and the Society were discussed.

Conference on International Developments in Heat Transfer

The second conference on international developments in heat transfer to be arranged by the Institution of Mechanical Engineers, the American Society of Mechanical Engineers and the Institution of Chemical Engineers will be held in London from 8th-12th January 1962. It will be a repeat of the Conference held in Boulder, Colorado, from 28th August to 1st September 1961. The basis of the Conference will be papers dealing with the fundamental aspects of heat transfer, but papers will also cover technology, nuclear energy and aeronautical sciences. Aspects to be covered broadly are radiation, convective heat and mass transfer, condensation and boiling, and conduction and diffusion. A preliminary programme of this conference may be obtained from the Secretary, The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, S.W.1.

International Flight Test Instrumentation Symposium

The second International Flight Test Instrumentation Symposium will be held at the College of Aeronautics, Cranfield, on 16th, 17th and 18th April 1962. Papers will be presented from the United Kingdom, Europe and the U.S.A., and there will be an exhibition of instrumentation equipment.

The Fifth Lanchester Memorial Lecture, 19th October 1961

The Fifth Lanchester Memorial Lecture, "From Ship Accompanying Waves to Shock Waves of Supersonic Aeroplanes," will be given by Monsieur R. Legendre of O.N.E.R.A., Paris, on Thursday 19th October 1961 at 6.0 p.m. in the Lecture Theatre at 4 Hamilton Place.

The lecture will be followed by a discussion.

The Seventeenth British Commonwealth Lecture, 16th November 1961

The Seventeenth British Commonwealth Lecture, "The Progress of B.E.A. and of European Air Transport 1946-61," will be given by Lord Douglas of Kirtleside, G.C.B., M.C., D.F.C., Chairman of British European Airways, on Thursday 16th November 1961 at 6.0 p.m. in the Lecture Theatre at 4 Hamilton Place.

The lecture will be followed by a discussion.

Acknowledgment

The Council acknowledge with thanks the gift of a collection of his personal papers and slides from Sir Roy Fedden, *Honorary Fellow*. Sir Roy has already given generously in the past to the Society from material accumulated in connection with his work on aircraft power plants.

Second Rocket Propulsion Symposium—Cranfield, April 1962

A second Rocket Propulsion Symposium, sponsored by the Royal Aeronautical Society, the British Interplanetary Society and the College of Aeronautics, is to be held at the College of Aeronautics on Thursday and Friday 26th and 27th April 1962.

The Symposium will follow the same pattern as the first highly successful Symposium held in January 1961, and will have as its main aim the encouragement, through formal and informal discussion, of the dissemination of unclassified ideas on all aspects of rocket propulsion, with particular emphasis on British work. The main theme of the 1962 Symposium will be "Rocket Combustion Chamber Processes." In addition to main papers on this topic short papers may describe new applications or experimental techniques, new aspects of production, development or research upon any aspect of rocket propulsion. Encouragement will be given to "new" authors wherever possible. As with the 1961 Symposium, the proceedings and discussion will be published in full.

Those intending to submit papers are asked to indicate the proposed title by **15th November;** if accepted a synopsis of some 200 words will be required by **15th January 1962.** Further information may be obtained from the Symposium Co-ordinator, Dennis S. Carton, Department of Aircraft Propulsion, The College of Aeronautics, Cranfield, Bletchley, Bucks. (Telephone: Cranfieldt 321).

Second Annual Dinner of the Rotorcraft Section

The second Annual Dinner of the Rotorcraft Section was held on Wednesday 6th September at the Dorchester, and was attended by about 450 members and their guests. The speakers were Major-General G. P. L. Weston, O.B.E., D.S.O., Director of Land/Air Warfare, who proposed "The Section," and Dr. Guyford Stever, President of the Institute of the Aerospace Sciences of America, who replied to the toast of "The Guests," proposed by W/Cdr. Brie, who presided in the absence of the Chairman of the Section, Professor J. A. J. Bennett.

DIARY

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

11th October
AGRICULTURAL AVIATION GROUP—Agricultural Aviation in New Zealand. G. G. Lindsay. 7 p.m.

12th October
MAIN LECTURE **at the Isle of Wight Branch**—Experiences in Constructing and Flying Bell's Recent VTO Aircraft. J. A. O'Malley, Jr. Saunders-Roe Club House, East Cowes. 6 p.m.

19th October
FIFTH LANCHESTER MEMORIAL LECTURE—From Ship Accompanying Waves to Shock Waves of Supersonic Aeroplanes. R. Legendre. 6 p.m.

30th October
HISTORICAL GROUP—Lecture by Sir Frederick Handley Page. 6 p.m.

1st November
Joint Meeting with Institution of Electrical Engineers. Generation of Power in Satellites. H. J. H. Sketch. **Institution of Electrical Engineers, Savoy Place, Victoria Embankment. 6 p.m.**

16th November
Seventeenth British Commonwealth Lecture. The Progress of B.E.A. and of European Air Transport 1946-1961. Lord Douglas of Kirtleside. 6 p.m.

17th November
MAN-POWERED AIRCRAFT GROUP. Aerodynamics of Man-Powered Flight. T. R. F. Nonweiler. 6 p.m.

ASTRONAUTICS AND GUIDED FLIGHT SECTION

16th October
Packaged Liquid Rocket Propulsion Systems. W. N. Neat and K. G. Page. 6 p.m.

14th November
A Comparison of the Control Problems of Missiles and Manned Aircraft. K. W. Smith. 6 p.m.

GRADUATES' AND STUDENTS' SECTION

23rd October
Club and Light Aircraft. D. Ogilvy. 7 p.m.

ROTORCRAFT SECTION

6th October
Integrated Flight Systems for Multi-Engined Rotorcraft Transports. N. Sullivan and J. A. Simpson. 6 p.m.

3rd November
Electronic Flight Information Displays for the Rotary Wing Aircraft. Wing Cdr. J. C. G. Bell. 6 p.m.

BRANCHES

10th October
Luton—Film Evening. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

11th October
Brough—Man-Powered Flight. B. S. Shenstone. Royal Station Hotel, Hull. 7.30 p.m.

12th October
Isle of Wight—MAIN SOCIETY LECTURE—Experiences in constructing and flying Bell's recent V.T.O. Aircraft. J. A. O'Malley, Jr., Saunders-Roe Club House, East Cowes. 6 p.m.

18th October
Coventry—The Scientific Uses of Satellites. P. J. Bowen. Herbert Art Gallery. 7.30 p.m.
Glasgow—Lecture or Symposium at Rolls-Royce.

25th October
Weybridge—The Supersonic Transport. Dr. A. E. Russell. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 5.45 p.m.

26th October
Bristol—Development of Para Visual Director. R. A. Chorley. Conference Room, Filton House, Bristol Aircraft Ltd., Filton. 6 p.m.
Christchurch—Navigational Aids. F. H. Bevan. Joint Lecture with the I.E.E. King's Arms Hotel. 7.30 p.m.
Gloucester—History of Silver City Car Ferry Operations. M. D. Day. Wheatstone Hall, Brunswick Road. 7.30 p.m.

3rd November
Brough—Annual Dinner-Dance. Spencer Arms, Hull.

6th November
Boscombe Down—Investment Castings for the Aircraft Industry. W. O. Beer. Lecture Hall, A. & A.E.E., 5.30 p.m.
Derby—Sixth Sir Henry Royce Memorial Lecture—Civil Aviation—A Forward Appraisal. P. G. Masefield. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

8th November
Brough—Eighth Sir George Cayley Memorial Lecture—The Aero-Engine in the Twentieth Century. Air Cdre. F. R. Banks. Royal Station Hotel, Brough. 7.30 p.m.

9th November
Bristol—Film Show in conjunction with the Documentary Film Group. Conference Room, Filton House, Bristol Aircraft Ltd., Filton. 6 p.m.

11th November
Glasgow—Symposium with Aircraft Bias. Scottish Aviation Ltd., Prestwick.

14th November
Luton—Modern Ship Design. J. Burton Davis. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

15th November
Christchurch—Rebuilding and Flying Historic Aircraft. Air Cdre. A. H. Wheeler. King's Arms Hotel. 7.30 p.m.

NEWS OF MEMBERS

N. K. BENSON (*Graduate*) formerly Head of Structures Laboratory, CIBA (A.R.L.) Ltd., Duxford, is now Scientific Collaborator, Institut fur Statik und Dynamik der Flugkonstruktionen der Technischen Hochschule, Stuttgart.

R. A. A. BRYANT (*Associate Fellow*) formerly Senior Lecturer in Mechanical Engineering, has been appointed Associate Professor in Mechanical Engineering at the University of New South Wales.

Sqn. Ldr. D. O. BUXTON (*Associate Fellow*) has retired from the Active List and the Joint U.S.A.F./R.A.F. Thor Force, and is now Manager of the San Simeon Corporation at San Simeon, U.S.A.

VISCOUNT CALDECOTE (*Associate Fellow*) formerly Executive Director, Guided Weapons, British Aircraft Corporation Ltd., has been appointed Deputy Managing Director and Chief Executive (Guided Weapons).

ALEX W. CAMERON (*Associate*) formerly Assistant Training and Education Manager, B.E.A., is now Selection Services Manager, B.O.A.C.

R. W. CARR (*Associate*) formerly Assistant Lecturer at Hatfield Technical College, is now Assistant Lecturer at the West Suffolk College of Further Education, Bu y St. Edmunds.

K. DE CROOS (*Associate*) formerly with Air Ceylon Ltd., is now Area Manager, Alitalia in Ceylon.

J. DEAKIN (*Graduate*) formerly Aerodynamicist in the Flight Test Office at Sir W. G. Armstrong Whitworth Company, is now Section Leader, Flight Test Planning and Analysis, Aerodynamics Department, Folland Aircraft Ltd.

Sqn. Ldr. B. DICKINSON (*Associate Fellow*) formerly Assistant Technical Instructor at the Empire Test Pilots' School, Farnborough, is now Chief Technical Instructor.

SIR GEORGE EDWARDS (*Honorary Fellow*) previously Executive Director, Aircraft, British Aircraft Corporation Ltd., has been appointed Managing Director. He ceases to be Managing Director of Vickers-Armstrongs (Aircraft) Ltd., but has been made Deputy Chairman of that Company.

A. H. ELDRIDGE (*Associate Fellow*) formerly Group Leader—Aerodynamics, Canadair Ltd., Montreal, is now Aerodynamics Engineer 'A', The Boeing Company, Transport Division, Renton.

F. B. GREATREX (*Fellow*) has been awarded the Wright Brothers Medal for 1960 by the American Society of Automotive Engineers for his paper "By-pass Engine Noise" presented last year at the S.A.E. National Aeronautic Meeting in New York.

Flt. Lt. R. B. G. HEDGECOCK (*Graduate*) has been posted from R.A.F. Technical College, Henlow, to R.A.F. Tengah, Singapore.

A. W. E. HOUGHTON (*Associate Fellow*) has been appointed Managing Director, Vickers-Armstrongs (Aircraft) Ltd.

D. S. HOUGHTON (*Associate Fellow*) formerly at the College of Aeronautics, is now Professor and Head of the Applied Mechanics Branch, Royal Military College of Science, Shrivenham.

JOHN O. KANE (*Associate Fellow*) formerly with General Dynamics Convair of San Diego, is now Design Specialist, Aerospace Division, the Ryan Aeronautical Co.

DAVID L. I. KIRKPATRICK (*Graduate*) formerly Aerodynamicist, Short Bros. and Harland, has been awarded an English-Speaking Union Branch University Fellowship at the University of Virginia.

Lt. Cdr. R. A. LANGLEY (*Associate Fellow*) formerly on the Staff of the Flag Officer (Home) at Lee-on-Solent, is now at La Escuela de Guerra Naval, Madrid.

J. R. LEACH (*Associate Fellow*) has been appointed to the Board of Sir George Godfrey & Partners Ltd., but retains the duties of Chief Engineer.

R. M. LECKENBY (*Graduate*) formerly Senior Wind Tunnel Tech. Asst., Blackburn Aircraft, is now in the Research Laboratories of Hovercraft Development Ltd., Hythe.

D. A. LESSWARE (*Graduate*) formerly stressman at Vickers-Armstrongs (Aircraft) Ltd., is now in the Technical Office at Sud Aviation, Toulouse.

Sqn. Ldr. J. E. LOXTON (*Associate Fellow*) has been posted from the Mechanical Engineering Department, R.A.E. Farnborough, to Royal Air Force, Chivenor.

Capt. MAURICE LUBY (*Fellow*) formerly General Manager and Vice-Chairman of Rotax Ltd., has been appointed Research Director of High Duty Alloys Ltd.

Sqn. Ldr. G. J. MACRAE (*Associate*) formerly O.C. Bomber Command Communication Squadron, is now at the Ministry of Defence (Joint Administrative Planning Staff).

F. C. PARKIN (*Graduate*) formerly Education Officer (Technical) at the No. 1 School of Technical Training, R.A.F. Halton, is now Project Planning Superintendent, Aircraft Equipment Division, de Havilland Aircraft Co. Ltd., Hatfield.

D. R. REES (*Graduate*) formerly Technical Officer with B.O.A.C. is now a Project Engineer with Hawker Aircraft Ltd., Kingston-on-Thames. (Correction from September JOURNAL, when Mr. Rees was incorrectly described as formerly with Fairey Aviation Co. Ltd.).

K. J. RIDDY (*Associate*) formerly Manager, Helicopter Unit, Chr. Salvesen and Co., Edinburgh, is now Managing Director, Rent-A-Copters Ltd.

Air Vice-Marshal N. C. S. RUTTER (*Fellow*) formerly Commandant, R.A.F. Technical College, Henlow, with the rank of Air Commodore, is now Senior Technical Staff Officer, Headquarters Bomber Command, Royal Air Force, High Wycombe.

J. T. SHEPHERD (*Graduate*) formerly at the College of Aeronautics, Cranfield, is now Systems Engineer, Elliott Brothers (London) Ltd.

TUDOR SPRINKS (*Student*) formerly Research Assistant in the Department of Aeronautics and Astronautics, has been appointed to a Research Fellowship in the Department of Applied Mathematics at the University of Southampton.

C. R. STEPHENS (*Graduate*) formerly an Aerodynamicist with Gloster Aircraft Co. Ltd., is now a Senior Aerodynamicist with Handley Page (Reading) Ltd.

Wing Cdr. A. STEWART (*Associate Fellow*) has retired from the R.A.F. and is now employed by the U.K. A.E.A. at Harwell as an Engineer Control Officer on Research Reactors.

GORDON STOCKDALE (*Associate Fellow*) has been promoted from an Assistant Development Engineer to Deputy Chief Inspector (Aero), Bristol Siddeley Engines, Coventry.

Sqn. Ldr. S. A. R. TAYLOR (*Associate Fellow*) formerly Officer Commanding Signals Squadron, R.A.F., Hullavington, is now Officer Commanding Signals Squadron, R.A.F., Manby.

J. C. WADDINGTON (*Graduate*) formerly Stress Engineer, Vickers-Armstrongs, Weybridge, is now a Stress Engineer with Beagle Aircraft.

Dr. P. B. WALKER (*Fellow*) formerly Head of Structures Department, R.A.E., has been appointed Consultant to the Director.

R. WATSON (*Graduate*) formerly demonstrator in the Aeronautics Department at Imperial College, is now a Temporary Lecturer Aeronautics Department at Queen's University, Belfast.

Sqn. Ldr. R. G. WELCOMME (*Associate Fellow*) formerly at HQ 2nd T.A.F. B.F.P.O. 40, has been posted to R.A.F. Dunholme Lodge for Technical Servicing Duties.

P. M. WELLS (*Graduate*) formerly Flight and Development Department, A. V. Roe & Co. Ltd., is now a Research Student at Aeronautics Laboratory, Cambridge University.

Group Capt. S. WROATH (*Associate Fellow*) formerly in the Technical Sales Department, Aero-Engine Division, is now Sales Project Manager (Military Engines), Aero-Engine Division, Rolls-Royce Ltd., Derby.

ZONTA AMELIA EARHART SCHOLARSHIPS

The 24th Annual Earhart Scholarships have been announced for the 1962 school year. The $2,500 grants are offered to qualified women for advanced study in aeronautical sciences. A degree in science qualifying a candidate for graduate work in aeronautical science is the basic requirement for a scholarship, plus evidence of exceptional ability and personal character. Candidates, or instructors wishing to recommend students, may obtain further information from Dr. Helen Pearce, 490 Oak Street, S.E., Salem, Oregon, U.S.A. Applications must be received by **15th February 1962.**

SUPPLEMENT TO THE OXFORD ENGLISH DICTIONARY

The following is the fifteenth list of aeronautical terms for the Supplement to the Oxford English Dictionary for which assistance in tracing earlier references is required. If members know of an earlier use than that given for any word, they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. Thanks are expressed to those who have already responded to these appeals.

kamikaze (Japanese suicide pilot)	1945	*New York Times*, 22nd April
laminar flow	1923	*Technical Report, A.C.A.* 1919/20
landing beam	1930	*Technical News Bulletin, Bureau of Standards*, July
landing flap	1936	*Technical Report, Aeronautical Research Committee*, 1934-5 I
landing gear	1911	*Reports & Memoranda* 59, November
landing light	1918	R. M. Pierce, *Dictionary of Aviation*
landing speed	1917	C. Grahame-White, *Air Power*
landing strip	1930	*Aircraft Engineering*, Jan.
launcher (device for launching missiles)	1945	*Aeroplane Spotter*, 18th Oct.
launching pad	1952	*Journal of the British Interplanetary Society*, January
launching site	1944	*Aeronautics*, August
let down, v. (=land)	1947	*Journal of the Royal Aeronautical Society*, LI
lift, sb. (=air-lift)	1948	*San Francisco News*, 13th August
liner (=air-liner)	1919	*Wonder Book of Aircraft*
liquid fuel (Rocketry)	1934	*Journal of the British Interplanetary Society*, April
localizer (beam, frequency, etc.)	1945	*Aeronautics*, February

Lecture Summaries

Rotorcraft Section

INTEGRATED FLIGHT SYSTEMS FOR MULTI-ENGINED ROTORCRAFT TRANSPORTS

N. SULLIVAN AND J. A. SIMPSON

To be given on 6th October 1961

The comparison between scheduled fixed-wing airline operations and present day helicopter activities is made in broad terms.

The flight control facilities necessary for scheduled helicopter operations into the city centre sites which exploit the unique capabilities of the helicopter are outlined, and standards of reliability required to match the fixed wing case are stated.

Existing flight instruments and systems, applicable to helicopter operations are reviewed, namely:

Helicopter Flight Directors
Rotor Speed Governors
Automatic Stabilisation Equipment
Automatic Coupling to approach Aids

The additional features required to meet the scheduled all-weather operation are given, and the flight system proposed for a future multi-engined helicopter is described.

Agricultural Aviation Group

AGRICULTURAL AVIATION IN NEW ZEALAND

G. G. LINDSAY

To be given on 11th October 1961

Mr. Lindsay's talk will survey the scope of the use of aircraft in agriculture in New Zealand. It will include the history of the development of the agricultural aviation industry there, some thoughts on the problems involved and how they may be tackled in the future.

EXPERIENCES IN CONSTRUCTING AND FLYING BELL'S RECENT VTO AIRCRAFT

JAMES A. O'MALLEY, JR.

Main Lecture to be given on 12th October 1961 at the Isle of Wight Branch

Some of the experiences encountered at Bell Aerosystems Company in the design, development, and flight testing of jet and ducted propeller V/STOL aircraft are reviewed.

Two jet aircraft have been flown to demonstrate basic types of VTOL machines. In the first case rotating engines were used to fly an Air Test Vehicle which the second case, the X-14, a modification of the propulsion system was prepared to divert the exhaust to the vertical. This thrust diverter was developed under the direction of the Aircraft company.

The requirements for control during hovering and transition flight were defined for these flight research aircraft in accordance with state-of-the-art capabilities. In the Air Test Vehicle, a separate supply was used to provide compressed air thrust. The X-14, on the other hand, utilised the compressor of the turbojet engine to provide this air supply.

The flight testing of these aircraft has substantially advanced the state-of-the-art and demonstrated the technical feasibility of the concepts. The successful flights of the Air Test Vehicle were made in 1954 and 1955. The X-14 was first hovered in February 1957 and was maintained in test flight throughout 1958 by Bell.

The X-14 was further tested by the N.A.S.A. using their own pilots. Subsequently, it has been modified to incorporate a variable stability system and the more powerful J-85 engines. The aeroplane is still on a flight test status to evaluate the influence of changing stability.

The experience accumulated from these programmes has provided a broad base of design background. The propulsion system design aspects were thoroughly explored in the development of inlets and thrust diverters. The stability and control problems were defined, safe levels established and controlled flight was demonstrated. New problem areas associated with jet impingement were explored and considerable information obtained relating to jet recirculation to inlets, suction or over-pressures on the aircraft near the ground, erosion problems at the take-off site and operating problems which might be encountered.

Working from this basis of flight test experience, the design of a full weapon system was undertaken in 1957 for a Navy deck ready VTOL interceptor. The VTOL capability made this aeroplane compatible with Air Force requirements and resulted in a joint programme for the D188A Fighter-Bomber. Both Navy and Air Force interest was maintained during a programme which led to a detailed mock up. This design required the expenditure of 600,000 engineering manhours of design and test programmes which included 3,750 hours of wind tunnel running time, the development of a new thrust diversion design, extensive weapon system applications and complete integration of the Avionics systems.

During this period of concentration on jet thrust applications parallel effort was maintained in the development of ducted propeller types of VTOL systems applicable to subsonic missions. In particular this type of propulsion system provides better hovering capabilities more suited to transport aircraft. A considerable effort was devoted to the detail design of a transport in the 12-15,000 lb. class. This aircraft was extensively tested to define the characteristics of the propulsion system and of the configuration.

Most recently this experience was applied to the development of an integrated transport design for the U.S. Tri-Service VTOL transport. This design incorporated Naval requirements, such as shipboard compatibility, with the rugged operations visualised by the Army. This design met all of the requirements specified by the Tri-Services and is currently under evaluation. Wind tunnel tests were made to substantiate the capabilities of the design.

Thus, the developments of the VTOL aircraft have proceeded from its study phases of ten years ago to demonstrated performance and capability to solve each of the technical problems which have been identified.

Rotorcraft Section

ELECTRONIC FLIGHT INFORMATION DISPLAYS FOR ROTARY WING AIRCRAFT

Wing Cdr. J. C. G. BELL

To be given on 3rd November

The application of electronic methods of display of flight information to the pilot and navigator of rotary wing aircraft is discussed. Much of the work described is applicable to other types of airborne vehicle but special problems of the rotary wing aircraft can be relieved by the use of the techniques described.

Data communication is discussed in relation to (*a*) the attitude control of an aircraft and (*b*) navigation and general systems management. It is clearly essential that the most important factor is the integration of the human pilot into the aircraft control loop as an operator or as a monitor of automatic systems such as stabilisers. The general objectives of any display system can be considered under the headings of efficiency, *i.e.* the elimination of redundant data, reduction of pilot fatigue, reliability and the reduction of bulk and weight. The first section of the paper concludes with a statement of a typical set of required parameters for such a display system. The three types of display, the contact analogue, the instrument analogue and the digital are considered, also use of situation or director display philosophy.

The second section deals with a generalisation of present day work in electronic presentation including both collimated and directly viewed displays. The devices used will be identified and briefly described. As an example, some typical present day systems will be discussed, including (*a*) the Bell Aircraft/A.N.I.P. Helicopter system; (*b*) directly viewed cathode-ray tube displays; (*c*) possible extensions of collimated cathode-ray tube displays; and (*d*) warning and secondary displays.

The final section outlines some possibilities for the future. The use of advanced electronic display tube techniques, coupled with micro-circuit waveform generation and computation should permit highly reliable and highly flexible communication of information. The weight and bulk of such systems should have substantial advantages over conventional methods and should prove a significant factor in the economics of rotary wing aircraft operation.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 OCTOBER 1961 NUMBER 610

The First Cierva Memorial Lecture

The Era of the Autogiro

BY

J. A. J. BENNETT, D.Sc., Ph.D., D.I.C., F.R.Ae.S.

(*Professor of Aerodynamics and Deputy Principal, College of Aeronautics*)

The First Cierva Memorial Lecture was given in the Lecture Theatre of the Society on 16th February 1961 with Dr. E. S. Moult, C.B.E., B.Sc., F.R.Ae.S., M.I.Mech.E., President of the Society, in the Chair. Introducing the lecturer, Dr. Moult said that, beginning in 1948, through the generosity of Wing Commander Graham Douglas, the Helicopter Association of Great Britain awarded a prize annually in commemoration of the great pioneer work of Juan de la Cierva in the field of rotary wing flight. When the Helicopter Association merged with the Royal Aeronautical Society in 1960 it was decided to institute a Cierva Memorial Lecture as a main event in the yearly calendar of the newly-formed Rotorcraft Section of the Society.

This was the first lecture of what he was sure would be an outstanding series and they were honoured by having with them for the occasion Dr. Carlos de la Cierva, son of the great pioneer. Professor Bennett had spent much of his working life associated with rotary wing aircraft and had been closely associated with Senor de la Cierva. He had been with the Cierva Autogiro Company for about 10 years, and for some seven years was head of the Helicopter Branch of Fairey Aviation; in America he was for a period a member of the British Air Commission and later, was Chief of Research of Hiller Aircraft. He was now Deputy Principal and Head of the Department of Aerodynamics at the College of Aeronautics.

1. Introduction

In this modern age when there is not only adequate direct lift for launching satellites and other space vehicles but a whole spectrum of ultra-slow take-off and landing devices applicable even to supersonic aircraft, the development of the Autogiro seems to belong to an entirely different era. The content of the First Cierva Memorial Lecture which it is my privilege and honour to give is an appreciation of the life and work of Juan de la Cierva. It was during the few years before his death in 1936 that I had the good fortune to know him and work with him and, as this period was indeed the zenith of his career, it may well be termed "The Era of the Autogiro."

Although an immediate outcome of Cierva's work was the advent of the helicopter, it was not Cierva's intention to use a mechanical transmission of power to the rotor in steady flight. The possibility of attaining the hoverability feature of the helicopter without the disadvantages associated with rotor torque was always a problem that Cierva thought to be capable of elegant solution. His main objective was to develop an aircraft that was capable of flying with a high degree of safety, not merely at altitude when cruising, but also at ultra-slow speeds close to the ground. This, as an aircraft designer, he achieved and, being also a test pilot, he was able to measure the extent of his achievement.

No doubt the ability of the helicopter to glide to a safe landing in the event of complete power failure gives the helicopter the same advantage as the Autogiro in this respect but not without a reduction of pitch and a change of flow through the rotor from the propeller state to that corresponding to auto-rotation. This necessary manoeuvre may be the responsibility of the pilot, in which case he may require to act quickly, or the reduction of pitch may be automatic in which case the sudden loss in lift may be embarrassing to the pilot, projecting him towards the ground when he wants to remain airborne. This, however, is only one of many problems associated with a powered rotor that are avoided in the Autogiro.

Cierva in three papers[1, 2, 3] given to this Society discussed the development of the Autogiro and the many improvements made as the work progressed, but much of the detail is described only in patent literature which is too extensive even to summarise here. The story of his early background and of some of his later achievements is contained in an autobiography[4]. A recent review of Cierva's work is given by Blanco[5].

2. Conception of the Freely Rotative Wing

In 1911, at the age of 16, Cierva with the help of two friends of his own age built two gliders and, in the following year, the first Spanish aeroplane that could fly. Before graduating in Civil Engineering from a Technical University in 1918, he had designed and built what he believed was the first three-engined aeroplane with tractor propellers. When it was finished and being tested, stalling during a turn caused the machine to spin and crash. This shook his faith in the aeroplane and he began to think that its limitations in regard to lift, stability and control would prevent it from being used extensively by other than professional pilots. He then directed his attention to alternative avenues of approach, which von Kármán once termed Die Seitenwege der Luftfahrt (Byways of Aeronautics)[6]. The helicopter and ornithopter were two of these, but they were considered by Cierva at that stage to be too complicated.

He decided that his objective could be achieved only (*a*) if the wings had a velocity relative to that of the framework and, (*b*) if the relative motion were maintained

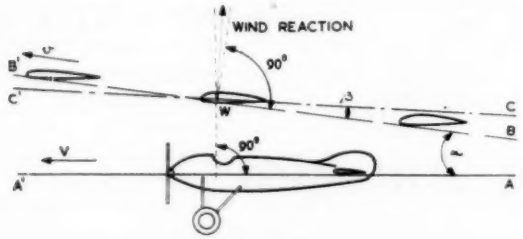

FIGURE 1.

independently of the application of mechanical power. The first abstract conception of such a device was an aircraft (Fig. 1) flying along a path AA' with speed V and having a wing W which, instead of being fixed to the fuselage, was given one degree of freedom to enable it to slide freely along a rectilinear path BB' indefinite in length but fixed in attitude relatively to the machine. The relative wind reaction on the wing would necessarily be inclined backwards with respect to the flight path AA' but if the angle α between the path AA' of the body and path BB' of the wing were greater than the angle of backward inclination of the reaction, the wing would slide forward along BB' with relative velocity v with respect to the machine, or along CC' with the vector sum of velocities v and V with respect to the air. The relative speed of the wing with respect to the air would then be greater than that of the machine, the more so the greater the attitude α of the wing to the flight path of the body (because v would increase with α). Cierva evolved a mathematical theory of this purely imaginary mechanism which seemed to him to comply with the two fundamental conditions he had enunciated at the outset.

The next step was to transform the imaginary rectilinear path of the wing into a closed circuit, which predicated rotational motion. He considered free rotation about a horizontal transverse axis (Fig. 2), a horizontal longitudinal axis (Fig. 3) or a vertical axis (Fig. 4). He discarded the first two on account of mechanical and structural complications and concentrated on rotation about a substantially vertical axis as being the most promising. He then examined the secondary problems of the new system, the most obvious being the dissymmetry of the periodic forces resulting from the relative velocity on the advancing side of the disc being greater than that on the retreating side. It appeared that two coaxial groups of freely rotating wings would be required, one group having the opposite sense of rotation to the other (Fig. 5). Rotors with separate axes, one on each side of the fuselage, were considered too cumbersome. Accordingly at this stage, in 1920, Cierva decided

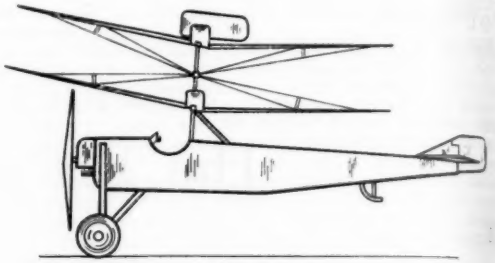

FIGURE 5.

to start experimenting with a machine embodying the new principle.

3. The Invention of the Autogiro

Having found that two coaxial rotors did not behave identically owing to unequal flow conditions at the two rotors, Cierva experimented next with only one rotor. He soon discovered the key which eliminated the problem of lateral unbalance caused by the dissymmetry of the relative velocities on the two sides of the disc. By giving the blades a further degree of freedom so that they could rise and fall freely about a hinge in response to variation of relative velocity and therefore of lift, he realised that he had solved at a stroke the main difficulty associated with the use of only one rotor. He was unaware that helicopter blades had previously been hinged at their root for another purpose, namely to relieve bending stresses. The use of a flapping hinge to compensate for the dissymmetry of periodic lift in a single rotor was, however, an original discovery, as helicopters required two rotors for torque balance.

To base an invention on a new use of a known device is never without patenting difficulties and Cierva's key discovery of the single rotor with articulated blades was no exception to the rule. Even the auto-rotative rotor had previously been described in a patent by Pescara[7] but no one before Cierva had found the secret of setting the auto-rotative blades at a positive pitch angle, thereby permitting the blade area to be reduced to a smaller fraction of the disc area than had ever before been possible. Consequently, a rotorcraft in a power-off vertical descent acquired a slower sinking speed than that of a conventional parachute of the same diameter and carrying the same load. That a rotor with a solidity of only a few per cent could have more support from the air than an impervious disc was one of Cierva's greatest achievements.

The Autogiro principle, which was concerned basically with blade auto-rotation at a positive pitch angle, was covered by Cierva's first application for a

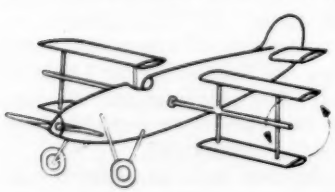

FIGURE 2.

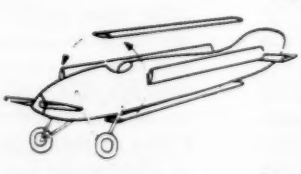

FIGURE 3.

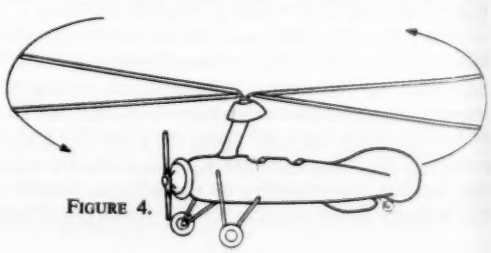

FIGURE 4.

FIGURE 6.

patent but, with little knowledge of patent law at the time, he allowed this early patent application to lapse in favour of the one relating to a single rotor with articulated blades. Convinced that no Autogiro could be successful without this particular feature, he abandoned the possibility of securing a very broad patent on the basic principle of the Autogiro. In trying to re-claim later what he had lost, most of his subsequent British patents were restricted in their application to rotorcraft with auto-rotative blades, Cierva having established a clear distinction between the Autogiro and the helicopter. In the United States, however, no such distinction was made and most of Cierva's American patents were considered to be applicable to helicopters as well as Autogiros.

4. The Mechanism of Auto-rotation

The Autogiro is basically a powered glider with rotating wings. The whole of the available power being applied to a forward propeller (Fig. 6), the necessary translational speed is maintained to keep the rotor revolving at zero torque. A large proportion of the rotor blade, acting as a windmill (Fig. 7) absorbs sufficient energy from the air to propel the remainder of the blade. In vertical descent, the tip portion of the blade is acting in the helicopter state, expending energy on the air. The resultant thrust in steady flight is along the axis of rotation because otherwise the rotor would not rotate at a constant speed. If the rotor tends to slow down, the increased upward flow through the rotor, due to the greater sinking speed, increases the windmill portion of

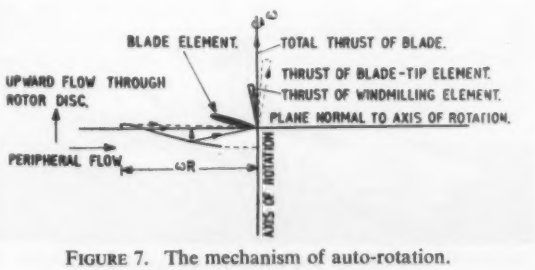

FIGURE 7. The mechanism of auto-rotation.

the blade, and the rotor is thereby accelerated. Conversely, if the rotational speed becomes excessive, the helicopter portion of the blade, where the flow is downward, increases in length, due to the slower speed of descent, and the rotor decelerates. Thus there is a continuous exchange of energy between the windmill portion of the disc where energy is absorbed from the air and the helicopter portion where energy is expended on the air. The Autogiro rotor is therefore partly a windmill and partly a lifting propeller, the blade elements in the windmill part contributing an accelerating torque and those in the helicopter (or lifting propeller) part a decelerating torque. The algebraic sum of the two component torques is zero at constant rotational speed.

In forward flight, the Autogiro being fundamentally a rotary-wing glider towed by a propeller, whenever the towing force of the propeller ceases it must descend. Manoeuvres to utilise the kinetic energy of the rotor are necessary to enable the Autogiro to take-off and land in still air without a forward run.

The inertia take-off technique enabled the Autogiro to bridge the gap between zero translational speed and that requiring minimum power. This was accomplished with precision and ease of control, thereby avoiding entirely the dynamic instability effects encountered by the helicopter in hovering flight. Most helicopters so far produced have, for safety reasons, not utilised their ability to climb vertically except within the ground cushion and have merely reduced to slow motion the take-off procedure of the Autogiro. For many uses, therefore, the ability of the helicopter to hover continuously and climb vertically has indeed appeared to be an expensive luxury. Momentary hoverability as in the Autogiro, assisted by the kinetic energy of the rotor, in contrast with the continuous hoverability of the helicopter, had a number of advantages, not the least of which was an ease of control. The control of a helicopter became relatively more complicated by the existence of rotor torque which required simultaneous compensatory movement of all controls due to their inter-dependence.

5. Mathematical Background

Much of Cierva's success in evolving a new method of flying must be attributed to his mathematical approach to every problem. He told me on one of the many occasions when we drove together from Half Moon Street to Hanworth before dawn, for early morning flight tests, that invention was merely a product of logical thinking, and that practically any engineer with a mathematical background could be trained as an inventor. Like his father, he required very few hours of sleep and he invariably worked at night for hours after midnight seeking a mathematical explanation of the test results that had been obtained during flight trials the previous day. It was characteristic of him to be found listening to radio music while filling large quantities of sheets of paper with equations and obtaining numerical results from his slide-rule.

Of the great variety of problems in which he was absorbed when I first knew him in 1930, the limitations

in Autogiro design that had been suggested by leading scientists of the day were uppermost in his thoughts. It had been suggested, for example, that flapping would cease to be damped and would become divergent in a dive at high tip-speed ratios, that the spiral path of the blade elements would inherently result in a higher profile power loss than that of a fixed wing and therefore that the Autogiro was inferior to what was termed the equivalent aeroplane of the same span, and that there was no justification for the low sinking speed claimed for the Autogiro compared with that of a parachute of the same diameter.

In the course of the next few years, however, the problems that were the most difficult were concerned mainly with vibrational engineering. Fatigue at the root attachment of the blade, so-called "ground resonance" due to the additional degrees of freedom when drag hinges were introduced, stick vibration when direct control of rotor tilt replaced conventional aeroplane controls, aeroelastic effects due to the flexibility of the blades and the inclined hinge effects associated with the inertia take-off technique were some of the practical problems that delayed production and prevented the Autogiro from being used more extensively during the lifetime of Cierva. Having isolated and solved so many mechanical problems of the rotating wing, Cierva had paved the way for the next step, the application of power to the rotor, first successfully achieved by licensees of the Cierva Autogiro Company the year after his untimely death in an air liner at the age of 41.

6. Airworthiness Aspects

By 1930 Cierva had completed a design handbook on the *Engineering Theory of the Autogiro* which was soon followed by a detailed account of the procedure for calculating rotor blade stresses. This second volume was entitled *Theory of Stresses in Autogiro Rotor Blades* and, although neither of the two books was published, the contents were widely read and applied both in this country and in America by designers of rotary wing aircraft. That helicopter rotors today have achieved a standard of safety as high as, and possibly higher than, that of aeroplane propellers may largely be attributed to airworthiness criteria developed from those established by Cierva.

The vulnerability to fatigue of the root attachment was the most difficult structural problem of the rotating wing. In one of the first Autogiros demonstrated in this country, a blade was shed in flight, fortunately without personal injury. The failure was due to periodic bending at the blade root in the chordwise plane and, although the drag hinge was introduced subsequently to relieve the root attachment of the so-called Coriolis effects, this was by no means the end of the story. Even after a large number of C.30 Autogiros had been produced and were in service throughout the world, fatigue cracks began to appear at the holes in the spar through which rivets or bolts held the spar root to a surrounding sleeve. This defect was later found to be accentuated by the use of solder as a filler between the two concentric steel tubes. Not until the spar tubes were manufactured with an upset end or collar integral with the spar was this particular fatigue problem surmounted.

Another crisis occurred when a military Autogiro failed to recover from a dive. The stability of the flapping motion of the blade was at first suspect but the very thorough investigation that followed this accident contributed much to the airworthiness of rotors. Rohrbach in Germany had suggested the use of a new Göttingen aerofoil that would improve the performance of the Autogiro and Cierva had readily adopted it as he wanted to improve the Autogiro's forward speed. Unfortunately, this aerofoil had a camber which produced a large periodic pitching moment, twisting the blades to such an extent that they periodically feathered elastically in response to the dissymmetry of forward flight. The result was that flapping was gradually replaced by elastic feathering as forward speed increased and the backward tilt of the tip-path plane started to diminish beyond a certain speed. The aircraft became more and more nose-heavy until, in a dive, with the stick full back, backward control was lost. This cambered aerofoil section (Göttingen 606) was also the cause of much vibrational trouble in the development of the Autogiro, and its replacement by the NACA section 23012 or 23015 with a substantially zero pitching moment was a vital step forward in the elimination of stick shake, and indeed in reducing the general level of vibration in the aircraft.

7. Use of a Fixed Wing

In view of present-day rotorcraft developments incorporating fixed wings in combination with a rotor, the satisfactory use of a small fixed wing in the C.19 Autogiro (Fig. 8) is of special interest. Although the main use of the fixed wing was for lateral stability and control by means of ailerons, it was designed to contribute sufficient lift to keep the angular speed of the rotor nearly constant in forward flight. At top speed the proportion of the all-up weight borne by the fixed wings was about one-fifth, their area being about one-third of the total blade area. The tip-speed ratio at maximum forward speed was two-thirds, *i.e.* about twice as great as the value used in later helicopters. Thus two-thirds of the retreating blade operated in a region of reversed flow, the sharp edge of the aerofoil becoming the leading edge. In this condition there was very little contribution of lift from the blades in the lateral azimuths. In spite of this the general level of vibration was not unpleasant.

This aircraft, the C.19, was later equipped with a

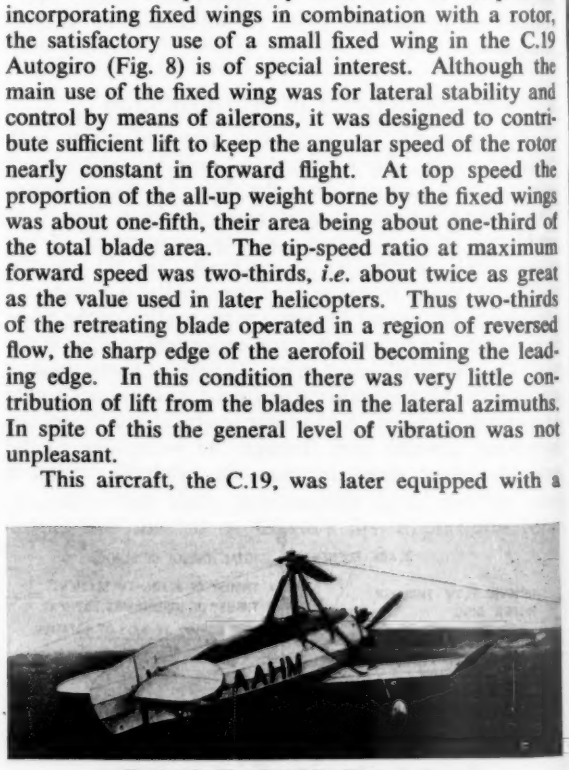

FIGURE 8. The C.19 Mk. IV Autogiro.

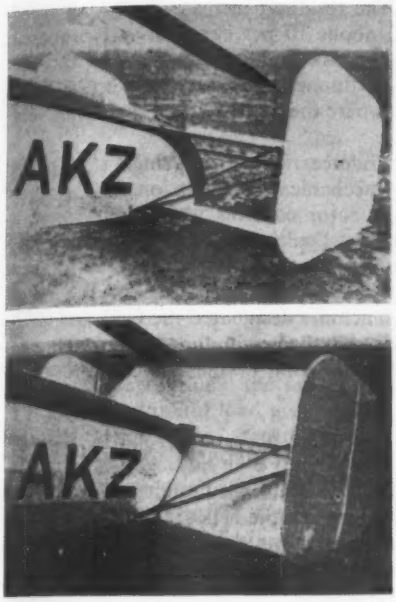

FIGURE 8(*a*). *Top left,* the deflector tail in flying position and, *below left,* the deflector tail in starting position.

FIGURE 8(*b*). *Above,* the C.19 Mk. III Autogiro, 1929.

tailplane having a large elevator (Fig. 8(*a*) and (*b*)) for deflecting the propeller slipstream upwards, thereby initiating rotation of the blades before take-off. It had also droop cables and blade inter-bracing cables. The deflector tail was replaced later (in the C.30) by a mechanical starter, and the cables were replaced by droop stops and drag hinge stops at the root of the blade.

As the conventional aeroplane controls of the C.19 were very much dependent on forward speed, they were not so effective as the tilting-hub control of the C.30 but, being isolated from the rotating system, they were relatively light and free from vibration. When the fixed wings were no longer required in the Autogiro for supporting the ailerons, they were abandoned but the comparative smoothness of the C.19 was lost, at least temporarily, with the increased proportion of lift taken by the rotor, especially as rotor vibration began to be transmitted to the stick.

The fixed wings were useful also as forming part of the structure for the undercarriage and their dihedral tips provided a simple method of correcting the destabilising moments produced by the high position of the centre of gravity with respect to the lateral centre of pressure of the fuselage and wheels. The fixed wings were considered to be working in a downwash of velocity equal to the induced velocity at the rotor, calculated as if the rotor were an aerofoil of span equal to the rotor diameter and supporting the same lift. Even today the Prandtl lifting-line theory on which this assumption is based is considered to give a very good approximation to the induced velocity of a rotor in forward flight.

8. The "Corresponding" Aeroplane

In his paper[2] to this Society in 1930, Cierva foresaw the possibility of Autogiros having a top speed of about 200 miles per hour while still retaining landing characteristics similar to those of the light Autogiros of that period. Although today the Rotodyne, utilising the Autogiro principle, confirms Cierva's claim, his views then were by no means generally accepted. He therefore considered improvement in forward speed of Autogiros as a challenge that required practical demonstration. This problem was of importance when I first met him in 1930 and resulted in the design of the C.24 Autogiro, built by the de Havilland Company at Stag Lane. This machine (Fig. 9) had similar features to those of the C.19, with a fixed wing and aeroplane controls, but it had a fuselage and engine similar to the Puss Moth with which it was compared in regard to top speed. Although the cleanliness of the design was somewhat spoiled by an experimental three-wheel undercarriage and large fins at the tail which were required for directional stability, the C.24 did achieve a top speed only about 10 miles per hour less than that of the Puss Moth. Thus Cierva demonstrated that the Autogiro was comparable in top speed with the very cleanest so-called "equivalent aeroplanes" of that era while retaining its inherent characteristics of shorter take-off, steeper angle of climb, lower minimum speed in level flight, steeper descent and improved landing. The rate of climb was about the same for both the Autogiro and the aeroplane.

The equivalent aeroplane, however, according to Cierva's definition was one not only of the same gross weight and power but also with the same parasite drag. The induced drag being substantially the same for an

FIGURE 9. C.24 Two-seater Cabin Autogiro, 1931.

aeroplane of span equal to the rotor diameter, the comparison therefore was mainly between the profile drag of a fixed wing and that of a rotor. The question of wing area was now the difficulty in making such a comparison because an aeroplane of wing area equal to the area of all the blades of the rotor would have had an exceedingly high landing speed. Even if the stalling speed of the corresponding aeroplane had been limited to only twice the minimum speed of the Autogiro in level flight, the wing area of the aeroplane would have been several times the blade area of the Autogiro. The rotor obviously compensated for its periodically higher relative speed by its low solidity[8] and it was this reasoning that led Cierva to visualise an Autogiro with a top speed of about 200 m.p.h. while retaining its slow-flying capability.

By 1934 when the secondary problems of the direct-control system seemed to him to have been solved satisfactorily, Cierva considered that the time was ripe for a definite step forward towards improvement in forward speed. There were two main problems. One was to decrease the body drag to a figure comparable with that of an aeroplane of similar top speed. The other was to design a rotor having a very low solidity, thereby allowing the rotor disc area to be large in comparison with the combined area of all the blades. The current Autogiro of that period, the C.30, had a rotor of 4·7 per cent solidity which was unnecessarily low for the top speed of that machine, since the tip speed to forward speed ratio at top speed was between 2·5 and 3, while previous Autogiro experience had shown that it could be as low as 1·5. This meant that if the C.30 were clean enough or had enough power to have a top speed of about 160 m.p.h., its rotor without modification could be considered as satisfactory for the higher speed and, assuming that there would be no change in gross weight, the low speed characteristics would remain the same.

A metal type of blade construction having been developed by the Weir Company, it was considered feasible to decrease the solidity by 20 per cent if necessary. As the top speed depended mainly on the blade loading and the slow speed characteristics on the disc loading, it was concluded that top speeds of around 200 m.p.h. could be achieved with a rotor of about 3·8 per cent solidity and disc loading of just over 2·0, *i.e.* about 20 per cent higher disc loading than that of the C.30 which was about 1·7. The resulting increase in sinking speed would have been about 10 per cent. It was proposed also to taper the blades in thickness towards the tip, thereby providing a thinner blade section over the outer part of the blade where the relative wind speed was very high.

A retractable undercarriage, a slim single-strut pylon inside which the mechanical transmission for the rotor starter and all the rotor controls would be housed, a rotor hub and blade articulations of compact design, an air-cooled in-line engine and a cantilever tail with faired attachments to the fuselage were some of the items specified for two machines designated the C.31 and C.32, both with a top speed in the neighbourhood of 200 m.p.h. Further information relating to these two proposals is given in Figs. 10 and 11.

9. The Westland Autogiros

Two variants of the Autogiro undertaken by the Company that now pioneers the helicopter in this country were noteworthy as attempts to design and construct machines that would have a wide variety of uses. Air taxi work, public transport, air mail service (particularly at night), air ambulance duties and Colonial service were particular objectives that could perhaps be met by a four-seater with accommodation for an extra passenger. In addition, an attractive two-seater Autogiro with side-by-side seating was required for the private owner. The larger of the two designs was known as the C.29 (Fig. 12) and the small Autogiro the C.L.20, which was derived from a French Autogiro, the C.L.10 (Fig. 13).

The C.L.20 with its Pobjoy Niagara 90 h.p. engine, although well up to specification in regard to attractiveness of layout, was somewhat under-powered. Not having the feature of direct take-off that was a new requirement of Autogiros after the C.L.20 had been built, it did not reach the production stage. Had there been a comparable engine available of greater power, this machine might well have been modified for direct take-off and fulfilled its promise.

The C.29, unlike the C.L.20, did not even reach the flight stage. With a Panther engine of 600 h.p., this Autogiro had a spring drive in the transmission system that provided power for starting the rotor. This resulted in difficult vibrational problems that unfortunately were not solved and the impression was given that severe

C.31
2-seater coupe machine
Napier Rapier Engine, Series IV (385 h.p., 16 cylinders)
Estimated empty weight, 2,000 lb.
Useful load, 1,000 lb.
(1 pilot, 1 passenger, 7 gal. oil, 60 gal. petrol, leaving 120 lb. for disposal)
Rotor diameter, 42 ft.
Load/sq. ft. of disc area, 2·15 lb.
Rotor tip-speed at sea-level, 515 ft./sec.

Estimated performance
Top speed at sea-level, 206 m.p.h.
Minimum horizontal speed at sea-level, 22 m.p.h.
Rate of climb, at about 100 m.p.h., 1,700 ft./min.
Practical ceiling, 25,000 ft.

FIGURE 10.

C.32
2-seater coupe machine
Gipsy-Six engine, maximum power at sea-level, 200 h.p.
Empty weight, 1,300 lb.
Useful load, 600 lb.
Rotor diameter, 34 ft.
Load/sq. ft. disc area, 2·06 lb.
Rotor solidity, 0·047
Rotor r.p.m. at top speed at sea-level, 270

Estimated performance
Top speed (sea-level), 180 m.p.h.
Minimum horizontal speed, 20 m.p.h.
Rate of climb, at about 90 m.p.h., 1,200 ft./min.
Practical ceiling, 16,000 ft.

FIGURE 11.

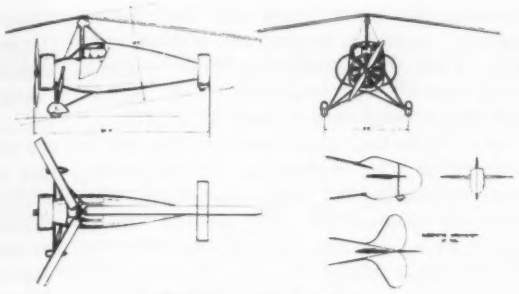

FIGURE 12. The C.29.

FIGURE 13. The C.L.10 Autogiro.

vibration was inherent in starting a rotor of 50 ft. diameter. Accordingly, the prospect of ever developing a rotorcraft of useful load greater than about half a ton became a subject of controversy which significantly hindered progress in rotary wing development long afterwards. The attention of Cierva at that time was devoted to the development of direct take-off which had its own vibrational problems and he considered the C.29 problem as one purely of an engineering nature that could be left entirely to the engine manufacturer to solve.

The mechanical starter was required to transmit only 100 h.p. to the rotor which was geared to rotate 6·7 times slower than the crankshaft of the engine. With helicopter rotors today using many times this amount of power, it is not easy to appreciate that 25 years ago many engineers regarded the C.29 problem as insuperable.

10. The C.30

The mere mention of the C.30 Autogiro (Fig. 14) evokes a feeling of nostalgia in almost everyone associated with rotary wing activities before or during the War years. It was the basic aircraft used at the Cierva Company's flying school at Hanworth where, in the year 1935 alone, 298 pupils, 37 of whom were trained *ab initio*, qualified as Autogiro pilots. Every available C.30 was used during the Second World War for radar calibration duties. The prototype G–ACFI especially was used by Cierva in many different modified forms over a number of years in a long and varied programme of experimental flying, including the first "jump" take-off trials.

The C.30 was the first "direct control" Autogiro and was demonstrated publicly by Cierva on 27th April, 1933. The prototype had a 5-cylinder Genet Major engine, but the pre-production and production versions had a 7-cylinder Genet Major of 140 h.p. Unlike the C.19, from parts of which the prototype was largely built, it had no fixed wings. Lateral and longitudinal control was effected from a "hanging stick" which tilted a universally-jointed hub and, as there was good directional stability except at very low forward speeds, there was no rudder. Many pilots considered that a rudder would have been an improvement for landing in no wind conditions, but the great simplicity of control perhaps justified its absence.

In 1934 and 1935 over a hundred C.30 Autogiros were produced by A. V. Roe in this country and a considerable number in France. The first public demonstrations of the C.30 attracted wide interest throughout the world and were generally considered to mark a new era in the history of aviation. The C.30s were subsequently used during Army manoeuvres, for the rapid transport of Staff officers, and were consistently landed and taken-off from terrain unsuitable for fixed-wing aircraft. They were used successfully by the police for observation and control of traffic and they were operated from ships. Other Autogiros based on the C.30 principle were built in America and elsewhere. They were landed and taken-off from city centres and a mail service was operated from the roof of the Philadelphia Post Office. Thus a considerable background of experience was accumulated both in this country and abroad with Autogiros having the general characteristics of the C.30.

The outstanding limitation was the ground run necessary for take-off in still air and it was this shortcoming that influenced Cierva and his associated companies to postpone further production until the direct take-off feature had been incorporated. The Autogiro flair-out landing was satisfactory enough, but Autogiros in America were provided with a rudder and a collective pitch control which allowed landings to be made with enhanced precision.

11. The Weir Single-Seater

In 1932, when the primary problems of direct control had been solved satisfactorily as a result of experiments with the C.19, it was considered that a most attractive type of Autogiro incorporating the new principle would be a cheap single-seater of about 500 lb. all-up weight

FIGURE 14. The C.30 Autogiro (Siddeley Civet engine).

and with a 50 h.p. engine, giving a power-loading of 10. Such a machine would have a very short take-off, a high rate of climb and a top speed of about 100 m.p.h. It could have many uses because of its safety, simplicity of control, ability to land and take-off in confined spaces and low cost.

Although the original conception was sound, it was soon realised that there were two outstanding problems. First, no engine of sufficiently low weight was available and, secondly, for low cost a two-bladed rotor was preferable to one with three or four blades. The effect of the number of blades on cost and weight was important enough to influence the technical and commercial success of an ultra-light Autogiro.

The most obvious method of obtaining 50 h.p. for a low weight was to develop a high speed engine of small cubic capacity and this was eventually undertaken. The two-cylinder engine, however, accentuated the vibrational problems which were already severe enough because of the two-bladed rotor and the extreme sensitivity of a small machine to sources of excitation. The C.28 Autogiro and its modified versions, therefore, were used as small flying test beds and an experimental development programme was undertaken in parallel with that of the C.30. Thus, when the two-bladed C.30 was demonstrated at Hounslow Heath in July, 1936, incorporating the new feature of "direct take-off," a derivative of the C.28, the Weir W.3, with a Pixie 50 h.p. engine, was demonstrated simultaneously utilising a similar technique.

12. Inclined Hinges

The angled drag hinge (Fig. 15) used by Cierva to provide an automatic change of blade pitch for direct take-off (Fig. 16) was one of many systems of inclined hinges investigated by him. Both or either of the blade articulations, previously known as the flapping hinge and the drag hinge, could be inclined with respect to each of three mutually perpendicular axes *Ox*, *Oy* and *Oz* (Fig. 17), thereby causing displacements about the hinge to have feathering chordwise and flapping components. Thus new terminology had to be introduced, the inboard hinge becoming known as the "delta hinge" and the outboard one as the "alpha hinge." The projections of the delta hinge on the three planes made angles δ_1, δ_2 and δ_3 respectively with the axes *Ox*, *Oy* and *Oz*. Similarly, the alpha hinge axis had three component angles α_1, α_2 and α_3 respectively in planes *xOy*, *yOz* and *zOx*. Thus the angled drag hinge originally used for direct take-off was described as an "alpha-one hinge" as it was inclined only in plane 1, *i.e.* *xOy*.

An "alpha-two hinge" was one that was inclined only in the plane *yOz*, or plane 2. This was a hinge that, for small displacements, gave substantially no change of pitch but ensured that drag motion was accompanied with flapping motion, the ratio between the two component displacements being dependent upon the angle of inclination, α_2. Such a hinge allowed mechanical damping to be eliminated without there being a tendency towards "ground resonance."

Another example of an inclined hinge was the "delta-three hinge" which, being inclined in plane *zOx* only, allowed cyclic pitch change or periodic feathering of the blade in combination with flapping. The use of a δ_3 inclination changed the azimuth position of the maximum upward displacement of the blade resulting from the dissymmetry of forward flight, and an appropriate choice of δ_3 resulted in the suppression of "lateral flapping," *i.e.* the blades reached their maximum amplitude in the forward azimuth. Thus the tip-path plane could be controlled automatically to have only a longitudinal tilt and no lateral tilt.

There were many combinations of inclined delta and alpha hinges that were of particular interest and it was possible also to separate mechanically the periodic coning harmonics from the other harmonics of the flapping motion[9]. An indication of the many different hinge arrangements tested on the C.30 Autogiro is given in Figs. 18, 19, 20 and 21.

13. The "Auto-dynamic" Rotor

Cierva soon discovered that the simple angled drag hinge was not a practical solution of the direct take-off problem. To utilise effectively the kinetic energy of the rotor for an inertia take-off, he could not allow friction or hydraulic dampers to act as a brake, a quick change of pitch being required, yet dampers were necessary to prevent "ground resonance." Consequently, a hinge arrangement like the "alpha-two" had to be selected that provided an alternative to friction dampers and allowed the blades to oscillate freely but, unlike the alpha-two

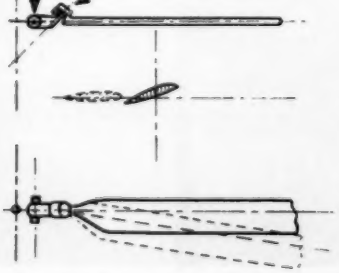

FIGURE 15. Angled drag hinge.

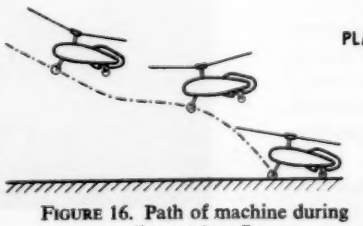

FIGURE 16. Path of machine during direct take-off.

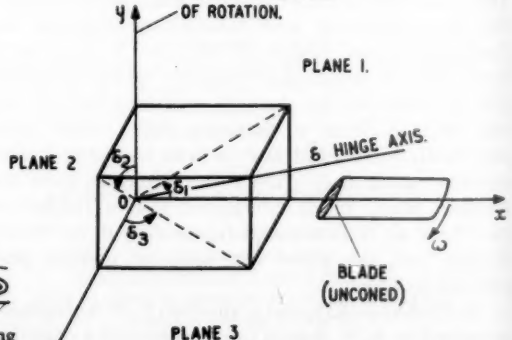

FIGURE 17.

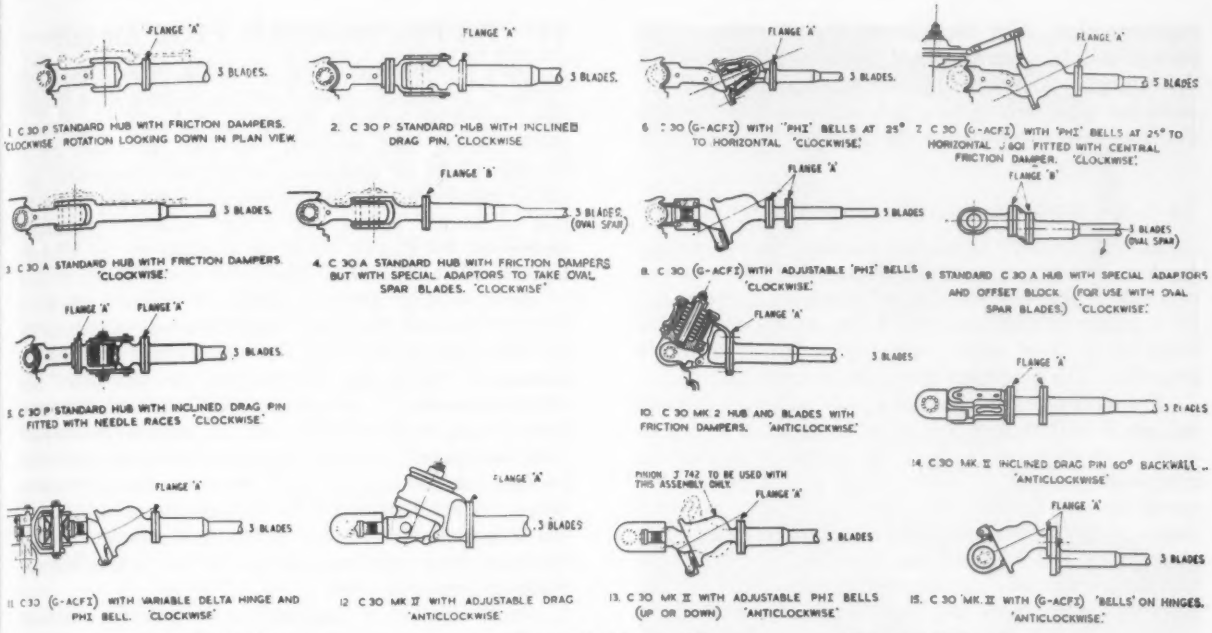
FLANGE 'A'
3 BLADES.
1. C.30 P STANDARD HUB WITH FRICTION DAMPERS. 'CLOCKWISE' ROTATION LOOKING DOWN IN PLAN VIEW.
2. C.30 P STANDARD HUB WITH INCLINED DRAG PIN. 'CLOCKWISE'
3. C.30 A STANDARD HUB WITH FRICTION DAMPERS. 'CLOCKWISE.'
FLANGE 'B'
3 BLADES. (OVAL SPAR)
4. C.30 A STANDARD HUB WITH FRICTION DAMPERS BUT WITH SPECIAL ADAPTORS TO TAKE OVAL SPAR BLADES. 'CLOCKWISE'
5. C.30 P STANDARD HUB WITH INCLINED DRAG PIN FITTED WITH NEEDLE RACES. 'CLOCKWISE'
6. C.30 (G-ACFI) WITH 'PHI' BELLS AT 25° TO HORIZONTAL. 'CLOCKWISE.'
7. C.30 (G-ACFI) WITH 'PHI' BELLS AT 25° TO HORIZONTAL. HUB FITTED WITH CENTRAL FRICTION DAMPER. 'CLOCKWISE.'
8. C.30 (G-ACFI) WITH ADJUSTABLE 'PHI' BELLS 'CLOCKWISE.'
9. STANDARD C.30 A HUB WITH SPECIAL ADAPTORS AND OFFSET BLOCK. (FOR USE WITH OVAL SPAR BLADES.) 'CLOCKWISE.'
10. C.30 MK.2 HUB AND BLADES WITH FRICTION DAMPERS. 'ANTICLOCKWISE.'
11. C.30 (G-ACFI) WITH VARIABLE DELTA HINGE AND PHI BELL. 'CLOCKWISE'
12. C.30 MK.II WITH ADJUSTABLE DRAG 'ANTICLOCKWISE'
PINION. J.742. TO BE USED WITH THIS ASSEMBLY ONLY.
13. C.30 MK.II WITH ADJUSTABLE PHI BELLS (UP OR DOWN) 'ANTICLOCKWISE'
14. C.30 MK.II INCLINED DRAG PIN 60° BACKWARD. 'ANTICLOCKWISE'
15. C.30 MK.II WITH (G-ACFI) 'BELLS' ON HINGES. 'ANTICLOCKWISE.'

FIGURE 18 (Nos. 1—5). FIGURE 19 (Nos. 6—10). FIGURE 20 (Nos. 11—15).

Hinge arrangements tested on the Cierva C.30 Autogiro.

hinge, provided the required change of pitch in response to torque. Such an arrangement, applicable only to two-bladed rotors, was found. A negative α_1 inclination gave freedom from ground resonance without dampers in a two-bladed rotor but not in a three-bladed one. The blades, however, had to be driven against their forward stops before take-off instead of being allowed simply to swing back naturally as in the case of the positive α_1 inclination. This was obviously a complication, as indicated in Fig. 21.

Moreover, the two-bladed rotor had too much vibration compared with the relatively smooth three-bladed C.30 rotor. Thus, although the principle of direct take-off was demonstrated publicly with such an arrangement, it was clear that further refinement was necessary. Cierva's objective was to develop a so-called "auto-dynamic rotor" that not only incorporated direct take-off but fulfilled the following requirements:

(*i*) automatic stabilisation in respect of both longitudinal and lateral dynamic stability;
(*ii*) automatic change of pitch with forward speed and altitude;
(*iii*) increased pitch momentarily during the direct take-off manoeuvre;
(*iv*) freedom from self-excited oscillations, such as "ground resonance;"
(*v*) absorption of "bouncing," *i.e.* vibration of the aircraft at a frequency equal to the number of blades times the angular speed of the rotor;
(*vi*) automatic locking in flight of the "phi" hinge, *i.e.* an additional hinge used only at take-off;
(*vii*) automatic decrease in pitch of the blades when the rotor brake was applied.

This was indeed an ambitious task and, although today, a quarter of a century later, we are aware that the first item in the foregoing list is a possibility[10] in helicopters without recourse to electronic devices, it has not yet been accomplished. In spite of the formidable nature of the problem he set himself, Cierva regarded it as a

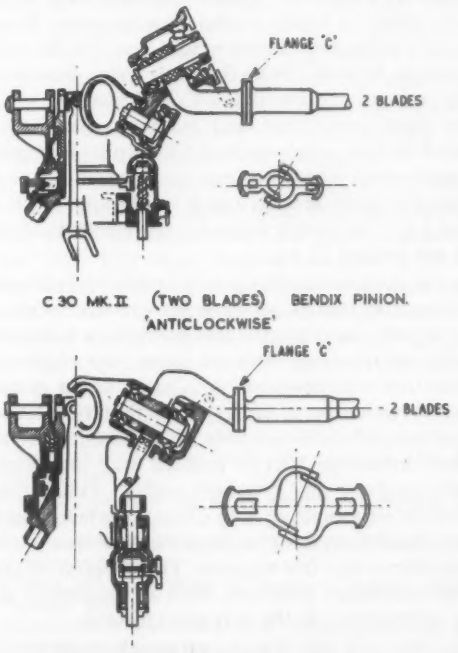

FIGURE 21. C.30 Autogiro.

challenge that, with his accumulated experience and background, he was capable of surmounting. The era of the Autogiro had been full of challenge and achievement but never was there a task so exacting as the one that remained unfulfilled at the close of that era.

14. An Approach to the Helicopter

In 1930, Cierva[2] mentioned the possibility of designing Autogiros that would have practically all the qualities of a helicopter. His conception of such an Autogiro led to a proposed machine, the C.26, with two engines mounted on fixed wings, each engine driving a tractor propeller. The propellers were contra-rotating.

The mechanical starter had a gear ratio such that the full power of the engine would be developed at an engine speed corresponding to about 80 to 85 per cent of the rotational speed of the rotor. Only one of the engines would be used to drive the rotor, namely the starboard engine if the rotor rotated clockwise when viewed from above. The differential thrust from the two propellers would automatically provide some compensation for the reactive torque from the rotor whenever mechanical power was applied to it during flight. The torque, however, would generally be quite small and could be balanced by means of a rudder operating in the propeller slipstream. A free-wheel drive was incorporated in the transmission from the engine.

Variable pitch propellers would be used and no attempt was made to achieve a high forward speed or payload. The C.26, proposed in 1931, was a single-seater with two Pobjoy "R" geared engines, one of them specially made to rotate in the opposite sense from the other. The estimated empty weight was 900 lb. and the gross weight 1200 lb. With the same rotor diameter and solidity as in the de Havilland C.24 Autogiro, and with similar fixed wings and tail surfaces, the C.26 was estimated to have a top speed of 130 m.p.h., its minimum horizontal speed would be zero, *i.e.* it could hover (with the propeller axes vertical) and it would take-off in 11 ft. at 20 m.p.h. The power taken by the mechanical starter would not exceed 12 h.p.

As the machine could operate both as a helicopter in vertical ascent and as an Autogiro in level flight and, being partially an Autogiro and partially a helicopter at attitudes intermediate between these two régimes, the configuration was described by Cierva as an Autogiro-helicopter. In answer to the objection that the pilot would be in an uncomfortable attitude when climbing vertically, or when hovering, Cierva pointed out that such an attitude, to have any practical utility, would only be adopted for surmounting high obstacles when taking off, it being possible to adopt a more conventional climbing attitude after a very few seconds. There would, of course, be some secondary problems, such as the supply of fuel to the carburettors at the extreme attitudes.

This was only one of many proposals made by Cierva and it is mentioned here because it was an early approach towards applying torque to the rotor in flight. Had this line of approach been pursued it might well have led to the eventual development of a compound helicopter.

15. The First Production VTOL Aircraft

Only a two-bladed rotor having been free from "ground resonance" when Cierva's inclined drag hinges were operated without dampers, and the two-bladed rotor having had inherent vibration of twice rotor frequency and of unpleasant amplitude throughout the entire speed range, it was necessary to find a solution to this difficulty before the jump take-off technique developed by Cierva could be applied to an aircraft suitable for production. The three-bladed rotor system of the C.40 (Fig. 22) was relatively free from vibration and the "ground resonance" difficulty was overcome by the provision of drag hinge dampers which damped the motion of the blades with respect to each other but which allowed the symmetrical oscillation of the three blades with respect to the hub to remain undamped. This configuration, which proved to be most successful, brought the Autogiro once more to the production stage. A batch of five C.40 Autogiros was supplied to the Royal Air Force shortly before the Second World War and they were used by the British Expeditionary Force in France in 1940.

As production of Autogiros in this country ceased at the beginning of the War and, as there was a military need for more, the Pitcairn PA–39 was developed in the United States as the result of a British requirement. It had features very similar to those of the C.40 Autogiro and flight tests were conducted by British pilots, including ship deck trials from a small platform at the stern of a merchant ship. The PA–39 Autogiro did not, however, reach the production stage, having been superseded in 1942 by the Sikorsky R–4 helicopter for anti-submarine duties.

16. Advent of the Helicopter

Although the helicopter derived its name from a descriptive title given to a sketch by Leonardo da Vinci and therefore had ancestral history dating back to the 15th Century, the family tree began to flourish only a generation ago with the conception by Cierva of the auto-rotative single rotor. As one writer has said, all early helicopters had one thing in common besides their

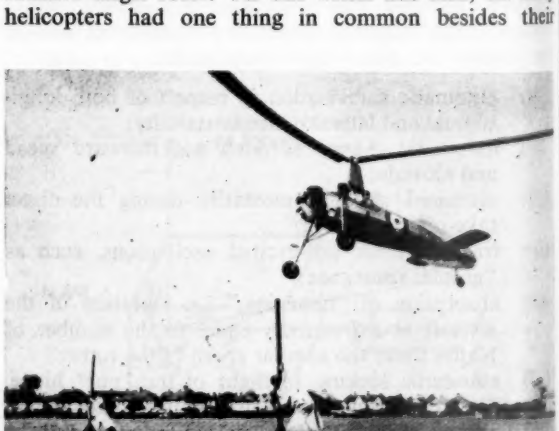

FIGURE 22. The C.40.

common failure: they all had at least two main-rotors. The reason was simply to achieve a balance of torque, but with the development of the Autogiro in which torque was no longer required, other basic problems of the helicopter could at last be studied under actual flight conditions. The family of helicopters developed by Sikorsky, having a single rotor, can be said to be descended directly from the Autogiro. The blades are hinged in a similar manner, longitudinal and lateral control of the tip-path plane is effected by movement of the control stick, self-excited oscillations are suppressed by adequate hinge damping, natural modes of vibration have to be different in frequency from the periodic excitations from the rotor to avoid resonance effects and the fluctuating spanwise load distribution on the blades in forward flight is of a similar nature to that in the Autogiro. The provision of a clutch and free-wheeling device, the use of a fixed wing in combination with a rotor and the effect, on take-off and landing, of superimposing collective pitch change were all explored in the Autogiro before the successful development of the helicopter. Indeed, in some respects, there has been a marked deterioration, *e.g.* in vibration and stability, from the standard achieved in the Autogiro over 20 years ago. Helicopters that are rough in operation at high pitch in forward flight are usually quite smooth at the same forward speed in auto-rotative flight.

Almost before the development of the single main-rotor family of helicopters had begun, it was argued that there was an upper limit of rotor size which would result in a maximum useful load of about half a ton and that at least two main rotors would be required if greater useful loads were contemplated. It was for this reason that the tandem rotor development was initiated in the United States. The argument was that, as the rotor weight would increase as the cube of the linear dimensions and the gross weight only as the square, the rotor weight would become such a large proportion of the gross weight, with increase in size, that the useful load would reach a limit and thereafter diminish. The square-cube law, however, erroneously assumed that the blade tip speed and coning angle had already reached their upper limits at their Autogiro values. Even today there is no basic reason why a single main-rotor should not suffice for the largest payloads contemplated in the next generation of helicopters. With the use of blade-mounted power plants, coning angle limitation has been overcome.

17. The Era of Powered-Lift

Just as the successful development of the auto-rotative rotor led to the advent of the helicopter, so the successful development of the helicopter is leading to the advent of powered-lift in a wider sense. The development of the gas turbine has been responsible for revolutionary new trends towards direct lift. As a result, vertical flight is no longer a unique feature of the helicopter and there is now a variety of direct take-off devices applicable even to supersonic aircraft. None of these devices is yet in a position to be in serious competition with the helicopter but there is a strong family resemblance.

FIGURE 23. Senor Juan de la Cierva.

In jet-lift aircraft, the rotors are enclosed in the engine but the principle of imparting downward momentum to the air, for direct lift, is the same and much of the technology is analogous if not identical. Powered lift is not confined to VTOL and STOL, of which the helicopter and Autogiro have been until now the leading exponents, but is being applied to GETOL's (aircraft dependent on ground effect for take-off and landing) and even to CTOL's or NTOL's (conventional or normal take-off and landing), in the latter cases to effect a decrease in wing area rather than to shorten the ground run.

Already, with aeroplanes tending to emulate the take-off and landing features of the helicopter, fixed-wing aircraft are becoming more and more dependent on powered-lift. The whole future of aviation is tending to revolve around the hub of direct-lifting devices and it is appropriate at this First Cierva Memorial Lecture to contemplate that it was Juan de la Cierva (Fig. 23) who paved the way towards a new era in aviation that is almost at hand—the era of powered-lift.

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Dr. Moult: Cierva had a rare combination of qualities. He was a scientist with a mathematical approach and yet was a practical engineer and a pilot. Because of this he had a full appreciation of the problems involved and he set about methodically to overcome them.

He paid great attention to safety and it was significant that the strength criteria established by Cierva were the basis of the airworthiness requirements of rotary wings of today.

Cierva worked out the geometry and the dynamics of the rotor blades and demonstrated the possibilities of auto-rotation long before the helicopter adopted this principle as a measure of safety. He foresaw the advantage of unloading the rotor in forward flight by the use of fixed wings. In addition, he was the first exponent of VTOL. All-in-all, the successful development of the helicopter and their thoughts about powered-lift owed a tremendous debt to Juan de la Cierva. And they owed a great debt to Professor Bennett for his lecture.

By custom there was no discussion at a Memorial Lecture, but he would ask Wing Commander Brie to propose a formal vote of thanks.

Wing Cdr. R. A. C. Brie, F.R.Ae.S.: This was a memorable and historic occasion. Not only had they been privileged to listen to a most authoritative exposition covering the whole period of the technical development of the Autogiro, but for the first time they had been able collectively to assemble there to pay tribute to its creator, Juan de la Cierva.

Dr. Moult had already referred to the fact that in years past they had aimed to keep Cierva's memory alive by means of the Cierva Memorial Prize Essay which was sponsored by the Helicopter Association. It was symptomatic of their happy liaison with the Royal Aeronautical Society that the Rotorcraft Section should now be able to perpetuate in a dignified manner and in a befitting setting the memory of so illustrious a name with a Main Lecture of this nature. In the past the Royal Aeronautical Society also well recognised the outstanding nature of Cierva's achievements by awarding him the Silver Medal in 1932, the Wakefield Gold Medal in 1934 and the Society's Gold Medal, posthumously, in 1937.

No title could have been more appropriate to the occasion than that given to the theme of the lecture: "The Era of the Autogiro." So vivid and factual an impression of an epoch-making period had been re-created by the lecturer as to evoke a feeling of nostalgia. In fact, it seemed hardly conceivable that almost 25 years had elapsed since Cierva was last with them, yet there were many present who retained cherished memories of that gallant and most human Spanish gentleman.

The Autogiro principle and its influence on modern conceptions of the rotary-wing art stood as a permanent monument to Cierva's genius. He died before the completion of his life's work; had it been otherwise they might well have avoided the complexities of design, construction and pilotage associated nowadays with hovering and vertical flight. In the days of Hanworth they had an Autogiro Flying School and it was indicative of the ease with which this aircraft could be flown, that their very first pupil in 1932 was aged 68. They got him solo, and he then bought his own Autogiro at a fairly low price. He used to fly around the countryside over the week-ends and on one occasion he brought a friend back for tea and their combined ages were 150 years. They also trained young people; the youngest was sixteen when they taught him to fly—too young to get a licence but he became a famous test pilot. They also taught women and there were a good handful who were really competent pilots. In some respects he thought they had drifted backwards because he was not aware of any amateur pilots of the helicopter.

Cierva's profound knowledge as a mathematician and engineer was such that whenever some new idea did not produce expected results an alternative solution seemed close at hand. Resourceful and possessed of a keenly analytical mind, he became a most skilful test pilot and was never satisfied that all was well with any new development until he himself had made the initial flight tests. Although the rapidity with which he conceived improvements was indicative of his mental alertness, he nevertheless displayed fantastic patience during preliminary trials with any new rotor system and would spend hours on taxying tests before essaying the first short flight.

A forceful character and a glutton for work, Cierva had the ability to impart to others his fanatical belief in the potentialities of slow speed flight. His infectious enthusiasm was an inspiration to all his associates and to those with whom he came into frequent contact. There were quite a number of pre-war Autogiro pilots present and members of the pre-war Cierva design and engineering staff, by all of whom he was much admired and respected. He was a fluent linguist and made short shrift of his mastery of English fairly soon after his arrival in this country. Of modest disposition and readily approachable, the early morning handshake with a weary and untidy engineer not only made amends for a tiresome night's work but was indicative of his conception of social behaviour. Possessed of a keen sense of humour, his flair for good conversation made him an asset at any party. To have been able to take a minor part in these proceedings and to make this personal contribution to the memory of an outstanding individual was for him both a privilege and an honour.

He had known James Bennett for many years; of his technical association with Juan de la Cierva; of the very able manner in which he successfully brought the C.40 jump take-off Autogiro to practical fruition; and of his beneficial work for the rotary-wing cause in general. There was nobody better qualified to present an appreciation of Cierva's life and work such as they had heard that night, and he felt that Professor Bennett had set a most worthy standard for those to follow in the years to come. On behalf of the Rotorcraft Section and all others present on this occasion, he had much pleasure in proposing a hearty vote of thanks to Professor Bennett for delivering this First Cierva Memorial Lecture.

Recent Developments in Photoelastic Coating Techniques

BY

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1. Historical Development

The original concept of measuring strains directly from the surface of a structure by coating it with a birefringent material is credited to Mesnager[1] (France, 1930), who was unable to obtain practical results at that time because of the lack of suitably sensitive photoelastic materials. Subsequent attempts were made by Mabboux[2] (France) in 1932, Oppel[3] (Germany) in 1936 and K. O. Scott (England) in 1949. In March 1953, Col. H. T. Jessop published in the JOURNAL of the Royal Aeronautical Society the results of some research into the feasibility of bonding modern plastics on to structures. In July 1954, Drucker[4] (U.S.A.) presented a paper in Brussels at the Convention of I.U.T.A.M. on research conducted at Brown University.

Recently, J. R. Linge published the results of some investigations made several years ago at the College of Aeronautics[5], and in Japan similar research has been done by K. Kawata[6]. Work in this field is also being carried out by J. R. Dixon at the National Engineering Laboratory, Glasgow.

In 1953 the first practical results in both elastic and plastic ranges of deformation, applicable to any part regardless of material, size or shape, were achieved in industrial applications by F. Zandman in France[7-10], where the photoelastic coating technique was first used as a practical tool directly in the field.

Since 1956 these techniques have been developed in the United States in collaboration with industry, and the resulting improvements in plastics, instrumentation and techniques have allowed the photoelastic coating technique to take its place alongside conventional two- and three-dimensional photoelasticity, electrical strain gauges, and brittle-lacquer techniques, as a fully recognised stress analysis tool[11].

The technique has become known, in industrial and scientific circles, by the popular name of "Photostress", and for convenience, the author will use this term subsequently.

NOTATION

E	Modulus of elasticity
μ	Poisson's ratio
t	thickness of plastic
δ	relative retardation of light wave
ε_1	major principal strain
ε_2	minor principal strain
σ_1	major principal stress
σ_2	minor principal stress
θ	angle of incidence of light in plastic
C	stress optical constant of plastic
K	dimensionless constant representing the optical strain sensitivity of the plastic

Suffixes

m	refers to metal or workpiece
p	refers to plastic coating
n	refers to normal incidence light
ob	refers to oblique incidence light

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2. Basic Principles

DEFINITIONS

Isoclinic: A black fringe observed in plane-polarised light, which is the locus of points at which the directions of principal stresses are constant and coincide with the axes of polarisation of the crossed polariscope.

Isochromatic: A line of constant colour which is also a line of constant maximum shear stress or principal stress difference.

The classical theories of photoelasticity are well known[12] and apply almost completely to photoelastic coatings, with a few slight modifications.

Briefly, in any material which exhibits artificial or temporary birefringence when stressed, relative retardation δ in normal incidence is related to principal stress difference by Newmann's equation:

$$\delta_n = (n_1 - n_2)\,2t = C\,(\sigma_1 - \sigma_2)_p 2t$$

$$\text{or} \quad \frac{\delta_n}{2tC} = (\sigma_1 - \sigma_2)_p \qquad . \quad . \quad . \quad . \quad (1)$$

(Note that the formula calls for $2t$ because light is reflected from the surface of the work piece, passing through the plastic twice.)

As the plastic coating follows exactly the deformation of the work piece to which it is bonded, then assuming the stress normal to the surface is negligibly small, it can be shown that:—

$$(\sigma_1 - \sigma_2)_m = \frac{\delta_n\,(E_m/1+\mu_m)}{2tK} \qquad . \quad . \quad (2)$$

where $K = CE_p/1+\mu_p$. K is generally obtained by calibration, or is given by the manufacturer for a given coating. Note that the maximum shear stress in the surface of the part τ is equal to one half $(\sigma_1 - \sigma_2)$. In

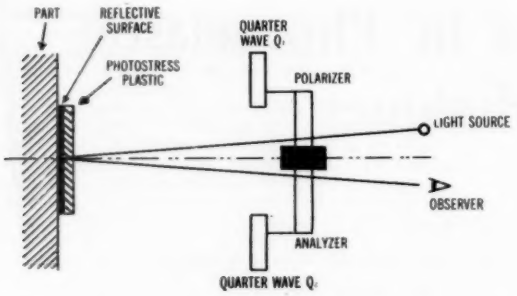

FIGURE 1. Schematic of reflection polariscope set-up for determining directions of ε_1 and ε_2. (Plane polariscope.)

applying Hooke's laws to equation (2), it can be seen that:

$$(\varepsilon_1-\varepsilon_2)=\delta_n/2tK \quad . \quad . \quad . \quad (3)$$

Having $(\sigma_1-\sigma_2)$ and the directions of σ_1 and σ_2, it is sometimes possible to determine the separate magnitudes of the principal stresses mathematically. Also, along any free boundary (hole, notch, etc.) where most failures occur, the stress normal to the boundary is zero; therefore the magnitude of the tangential stress is given directly by the fringe value at the boundary.

In cases where the individual principal stresses must be determined experimentally, a photoelastic analysis made with polarised light passing through the plastic coating in oblique incidence (*see* Fig. 3) will provide the separate magnitudes and signs of σ_1, and σ_2[8, 10, 13, 14].

Combining one normal and one oblique reading, it can be shown that, with light passing through the plastic at 45°

$$\sigma_1=\frac{E_m}{tK(1+\mu)}\left(\frac{\sqrt{2}}{2}\delta_{ob}-\frac{\delta_n}{2}\right) \quad . \quad . \quad (4)$$

$$\sigma_2=\frac{E_m}{tK(1+\mu)}\left(\frac{\sqrt{2}}{2}\delta_{ob}-\delta_n\right) \quad . \quad . \quad (5)$$

(It has been assumed for simplification of formulae, that $\mu_m=\mu_p=\mu$.)

3. Experimental Technique

The photoelastic coating may be applied by brushing a liquid plastic on the surface of the structure and

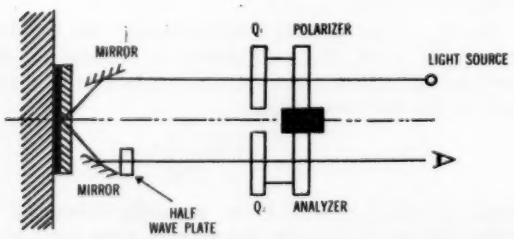

FIGURE 3. Set-up for measurement of the separate magnitudes and signs of principal strains ε_1 and ε_2 by oblique incidence.

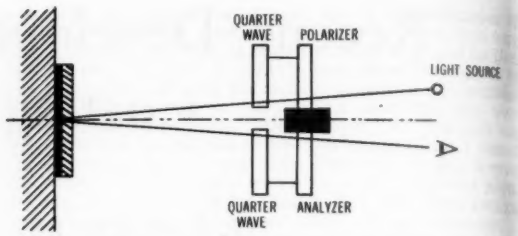

FIGURE 2. Set-up for measurement of maximum shear strain ε_1-ε_2. (Circular polariscope.)

polymerising it by applying heat to the part. Alternatively, a prefabricated flat or contoured sheet of plastic can be bonded to the structure at room temperature. (Figs. 4(*a*)–4(*d*).)

The maximum strains measured can be of the order of 3 to 50 per cent, depending on the type of plastic used[10]. The 3 per cent maximum elongation plastic is generally used for metal parts, and has a fringe value of approximately 1,000 micro-inch/inch/fringe for a 0·120 in. thick sheet ($K=0{\cdot}1$). The 50 per cent maximum elongation plastic is generally used on other plastics, rubber, canvas, fabrics and other material having high inherent elongation properties. It has a fringe value of approximately 5,000 micro-inch/inch/fringe for a 0·120 in. thick sheet ($K=0{\cdot}02$).

The calibration of plastic is usually effected by applying dead weights to the end of a cantilever which is coated with a small strip of plastic cut from the same mould or sheet as the plastic bonded to the structure.

The strain on the upper surface of the bar is easily calculated for a given load. The birefringence δ produced by this load is measured, and application of equation (3) gives the K factor, after application of a bending correction factor. (This point is discussed later.)

4. Instrumentation

Two basic instruments have been developed for strain analysis; a microscope-type reflection polariscope (Fig. 5) for study of very small parts or regions of high strain gradient (holes, fillets, notches, and so on), and a large field polariscope (Figs. 1, 2, 3 and 6) for measurements on fairly large structures.

Both instruments provide the directions of principal strains within ± 2 degrees and the magnitude of maximum shear strains $(\varepsilon_1-\varepsilon_2)$ to within ± 10 micro-inch/inch for 3 per cent elongation plastic of 0·120 in. thickness. Both instruments have oblique incidence attachments for the separation of principal strains.

Fractional orders of relative retardation are determined by use of a Babinet Compensator on the microscope polariscope; by goniometric compensation (Tardy method) on the large field instrument. Both instruments are designed so that they may be used in conjunction with stroboscopic light sources for dynamic measurements, or with photographic equipment (still or movie, and with the large field instrument, high speed).

FIGURE 4(*a*). Pouring the mixed plastic and hardener into mould, after allowing the exothermic reaction to raise the temperature to 90°-100°F.

FIG. 4(*b*). Removing the semi-polymerised sheet from the mould.

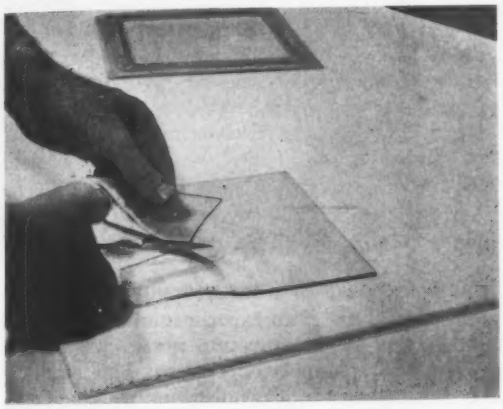

FIGURE 4(*c*). Cutting the sheet to size.

FIGURE 4(*d*). Contouring the plastic to the part.

FIGURE 5 (*left*). Small Field (microscope) Polariscope.

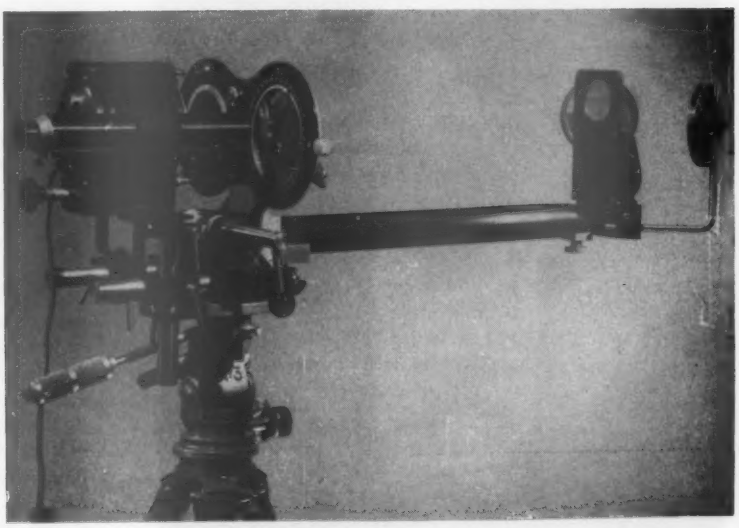

FIGURE 6. Large Field Polariscope with oblique incidence attachment.

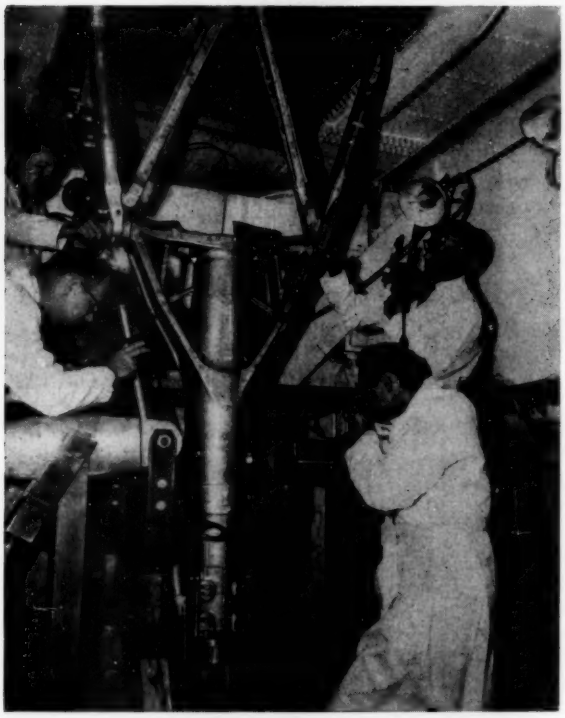

FIGURE 7. B.58 "Hustler" landing gear being stress-analysed under static load.

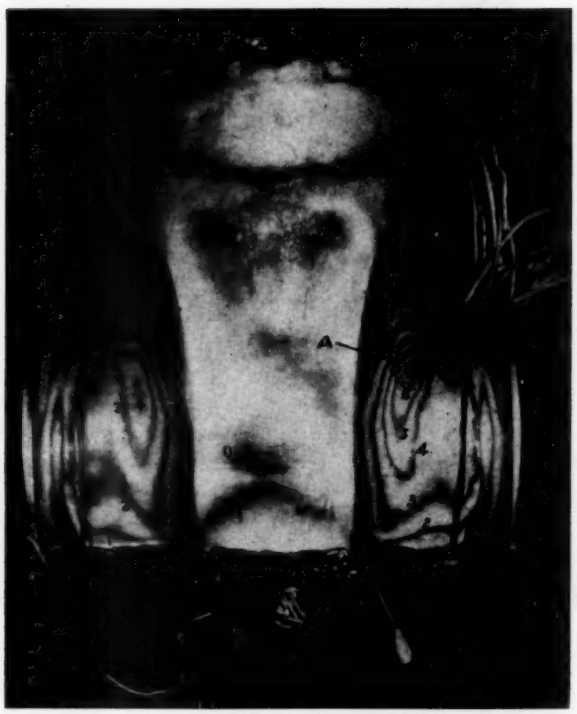

FIGURE 8. Landing gear front axle carrier under 40 per cent vertical load and 30° taxi turn conditions. Maximum shear stress at A ($6\frac{1}{2}$)$=\frac{1}{2}(\sigma_1-\sigma_2)=123{,}500$ p.s.i.

5. Photostress Applications in the Field of Aeronautics

5.1. STRESS ANALYSIS OF AN AIRCRAFT LANDING GEAR

The photoelastic coating method has been applied to a large number of structural problems in which distributions of maximum shear stresses were required. The aircraft landing gear shown in Fig. 7 is an illustration of a large structure under extensive analysis. The entire landing gear was coated with partially polymerised plastic sheets of 0·075 in. thickness, contoured to the shape of the structure. Many separate sheets were used, each carefully cut to butt neatly against its neighbouring sheets.

After complete polymerisation (24 hours at room temperature) the structure was loaded statically in increments of 10 per cent of the estimated ultimate design load. Isochromatic and Isoclinic fringes were observed and recorded by two methods, namely (*i*) by photography and (*ii*) by tracing the fringes directly on the coating with a grease pencil and subsequently transferring these patterns on to tracing paper.

Figure 8 shows a region of critically high stress. The test was halted at 40 per cent of the estimated design load when it became obvious that the part shown in Fig. 8 required modification in order to sustain full load.

5.2. STRESS ANALYSIS OF A ROCKET MOTOR CASE

The stress analysis of an experimental stainless steel double-wrap spot-welded pressure vessel was undertaken, using both photoelastic coatings and electrical resistance strain gauges. Stress distributions were determined for several characteristic areas of the vessel.

The coating consisted of two contoured sheets of 0·056 in. and 0·053 in. thickness. No initial birefringence was present after polymerisation. Another area of the specimen was covered by a much thinner layer of plastic (0·010 in.) by brushing the liquid resin directly on to the test surface. This section was used exclusively to observe the plastic range of deformation —thin, brushed-on coatings being particularly suitable for plastic strain measurements, as better adhesion is achieved. (It should be noted that small coating thicknesses give adequate birefringence, as strains are high in the plastic range of deformation.)

In addition to the coating, 1/4 in. gauge length strain gauges were applied at four critical locations.

The casing was loaded by internal water pressure in 100 lb./in.^{2} increments up to failure, which occurred at 1,500 lb./in.^{2}

Figure 9 shows the fringe pattern obtained at 500 lb./in.^{2}. Fig. 10 shows the Photostress and strain gauge readings compared with calculated values for one area of the casing and Fig. 11(*a*) and (*b*) shows the casing after rupture, with associated fringe patterns of plastic deformation.

The recorded reproducibility of strain measurements for the photoelastic coatings was ± 30 micro-inch/inch, and for the strain gauges ± 10 micro-inch/inch. Reinforcement effects by the plastic were calculated, but the effect was insignificant both theoretically and

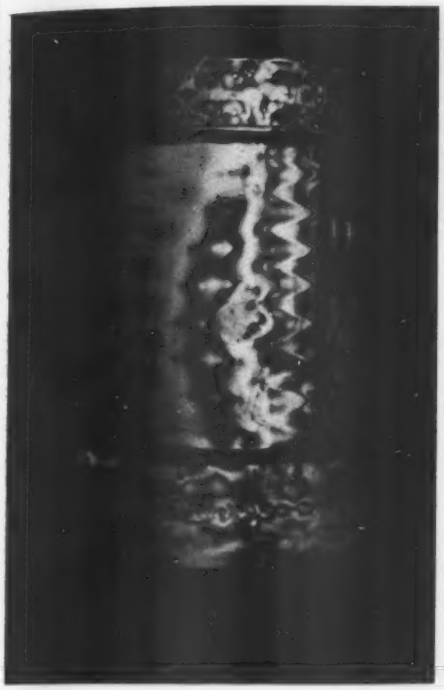

FIGURE 9. Photoelastic pattern at 500 p.s.i. pressure.

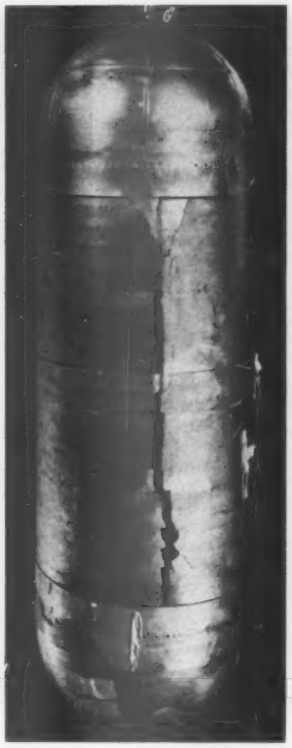

FIGURE 11(*b*) (*above*). Photoelastic pattern of permanent strains after rupture.

FIGURE 11(*a*) (*left*). Pressure vessel after rupture.

experimentally. It was found that classical pressure vessel formulae could be applied as a satisfactory first approximation. Burst pressure agreed well with calculated values. Strain gauge and Photostress readings agreed within ± 100 micro-inch/inch.

5.3. STRESS ANALYSIS OF A MISSILE TAIL SECTION

The purpose of the test was to find (*i*) the location and magnitude of stress concentrations, and (*ii*) the general strain distribution in the elastic and elasto-plastic ranges of deformation under simulated flight loads.

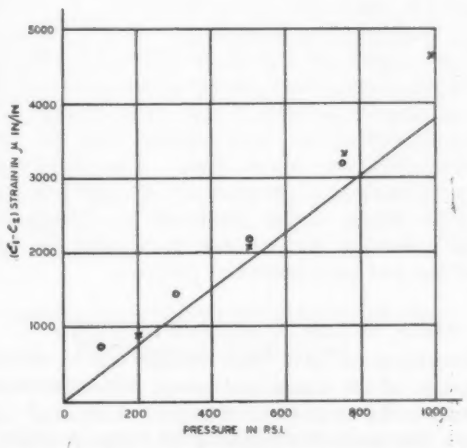

FIGURE 10. Comparison of calculated and experimental values.
——— Calculated value
○ Photoelastic coating
× Strain gauges

Previous strain gauge tests had shown no critical points due to the fact that high stresses existed only in four very limited areas, the remaining areas being subject to very low strain levels.

Two of the aluminium alloy fins were coated with Photostress plastic and analysed. Maximum shear strains, separate values of principal strains, strain gradients, strain concentration factors and directions of principal strains were measured.

Figure 12 shows the missile in its test platform with microscope polariscope in position. Fig. 13 shows the fringe pattern observed in the left fin, with stress concentrations clearly indicated.

The analysis made it possible to recommend certain design changes which would decrease both weight and manufacturing time and at the same time increase the strength of the structure.

5.4. STRESS ANALYSIS OF TURBINE BLADE CORROSION PITS

After 50 hours of continuous running in a gas turbine, several of the turbine blades were removed and coated with Photostress plastic in order that the effect of stress concentrations produced by small corrosion pits on the ultimate strength of the blades could be determined. The blades were loaded in a tensile testing machine and the stress concentrations around the corrosion pits measured (*see* Fig. 14).

FIGURE 12. Guided missile in test platform with small-field meter in position.

FIGURE 13. Photograph of high stress-concentration in left fin.

6. Other Applications of Photostress

6.1. PLASTIC YIELD STUDIES

The fact that plastics can now be produced with elastic properties that may be varied to produce linear elastic ranges varying from 3 per cent to, if required, over 100 per cent, means that the photoelastic coating technique has reached a stage of development where it can be used as a powerful tool in the study of the plastic and elasto-plastic behaviour of materials. Some work has already been done in this field, including a preliminary investigation into the true yield point of metals[25], and a study of plastically deformed grain boundary strains.

6.2. RESIDUAL STRESSES

Several successful studies of residual stresses in cast structures have already been carried out[15]. The method used was to coat the part and then section it, thus producing a fringe pattern due to the relieved stresses, which could then be analysed.

6.3. THERMAL STRESSES

Recent industrial development of composite aluminium and iron automobile engines has brought with it a host of thermal stress problems. A few of these have been investigated[16, 28], and the Photostress technique appears to be suitable for the investigation of such problems. Care has to be taken, however, to correct for additional strains produced in the coating by differing coefficients of thermal expansion of the coating and the structure.

6.4. FATIGUE AND CRACK PROPAGATION

The plastics used for modern photoelastic coatings have a considerably higher fatigue life than most industrial materials, and consequently may be used, in conjunction with stroboscopic light sources, to study fatigue and crack propagation problems. It should be noted, however, that reliable quantitative readings in the direct vicinity of a crack are difficult to obtain due to "displacement strains" in the plastic produced when a crack appears beneath a still intact coating. Such strains, of course, are not associated with any corresponding stress in the structure. This disadvantage, however, becomes an asset in the detection of cracks, the high fringe orders produced by "displacement strains" allowing thin coatings to be used for service inspection and acceptance test purposes.

6.5. STUDY OF ELASTIC AND PLASTIC WAVES

Investigations have been carried out to determine the nature of the elastic and plastic waves produced in aluminium by explosive charges[17]. A high speed camera was used which gave good fringe resolution at a speed of 500,000 frames/second. Tests of this type would appear to offer a useful means of investigating many of the problems which are arising in the new field of the explosive forming of metals.

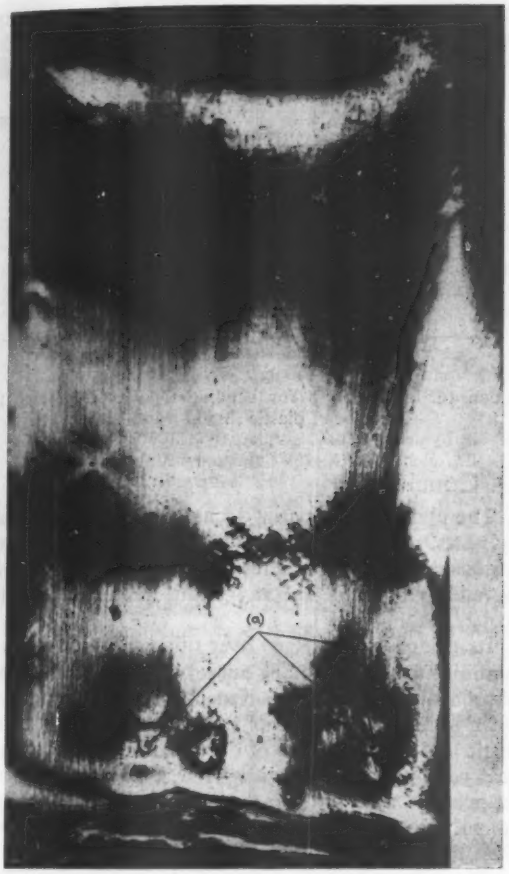

FIGURE 14. Fringe patterns produced by stress concentrations around corroded areas (*a*) of a turbine blade.

6.6. STRESSES IN VISCO-ELASTIC MATERIALS

Many of the new rocket solid fuels are visco-elastic, and stress problems of an extremely complex nature can occur under the temperature and pressure gradients involved, which can have a direct effect on the combustion stability of such fuels. An analysis of such a visco-elastic fuel has been carried out to study stresses under certain temperature and pressure gradients, and useful quantitative data were obtained[18]. With materials of this type, reinforcing effects of the plastic can be significant, and care must be taken to take such effects into account.

7. Advantages and Limitations of the Photostress Technique

7.1. ADVANTAGES

A photoelastic coating behaves as an infinite number of strain gauges of infinitely small gauge length distributed continuously over the surface of a structure. Stress readings may be made directly on a structure subject to operational loading conditions.

Analysis can be made on practically all construction materials, such as wood, concrete[19], metals, glass, rubber, plastic, and so on.

Plastics can be produced to withstand almost any required elongation, with linear birefringence/strain characteristics, enabling data to be obtained in both elastic and plastic ranges of most structures.

Still, movie or high speed photography may be used, as well as black and white or colour television to study static and dynamic loading conditions.

Maximum shear strains and directions of principal strains may be determined directly. Additional readings in oblique incidence give the separate magnitude and sign of the individual principal strains.

Systematic measurements over a period of four years have shown that the sensitivity of the plastic remains constant and is relatively insensitive to humidity effects, enabling it to be used for long term measurements of structures such as dams, bridges, and so on.

7.2. LIMITATIONS

Strains cannot be measured in areas not accessible to illumination. (Residual strains, however, can be measured if a part, stressed beyond the elastic limit, becomes accessible to light after dismantling.)

The strain-optical constant K varies for temperatures outside the range -40 to $+95°F$. Corrections should be made for readings taken outside this range (*see* Fig. 15).

If readings are taken at a temperature which differs widely from the temperature at which the coating was bonded to the structure, parasitic birefringence will be produced around edges of the plastic due to the difference in expansion between the plastic and work piece. In such a case the strain in the structure can be calculated from the Load and No-load birefringence[20, 21, 22].

The photoelastic coating technique measures only surface strains.

For cases where the maximum shear theory may be applied as a criterion for structural failure, normal incidence readings will often give sufficient information for prediction of failure and the designing of a structurally safe part. However, the fringe pattern only gives the maximum shear strain *in the plane of the*

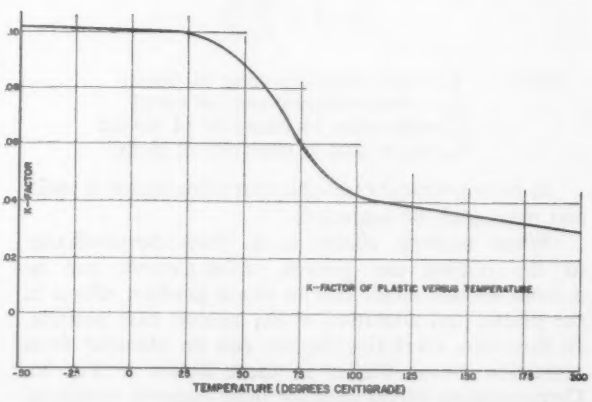

FIGURE 15.

coating, and this is not necessarily the maximum shear strain at any point.

We have justifiably assumed that σ_3, the stress normal to the free surface of the structure is zero. As the maximum shear stress is equal to one half the difference between the algebraically largest and smallest principal stresses, if σ_1 and σ_2 are of opposite sign (*i.e.* one tension and one compression), then the maximum shear stress is $\frac{1}{2}(\sigma_1 - \sigma_2)$ and will be in the plane of the surface. However, if σ_1 and σ_2 have the same sign (both tensile or compressive), then the maximum shear stress will be given by $\frac{1}{2}\sigma_1$ or $\frac{1}{2}\sigma_2$, as $\sigma_3 = 0$, and will be in a plane perpendicular to the surface. In such cases, the separate magnitudes of the principal stresses will have to be determined by an additional reading in oblique incidence.

The accuracy of strain determination depends not only on the accuracy of measurement of birefringence, but also on the accuracy with which the coating thickness can be determined (*see* equation (3)). For flat sheets and sheets contoured over parts that do not contain sharp changes of curvature the thickness will not vary more than 2 or 3 per cent. For sheets contoured over awkwardly shaped parts, and for coatings that have been polymerised directly on to the surface, local variations in thickness may be considerably greater than this. In such cases, the thickness must be known at every point at which readings are taken. For directly polymerised thin coatings, the thickness may be measured optically (the small field polariscope contains a fixture for doing this) or mechanically with a micrometer. With contoured sheets it is most easily accomplished by allowing the plastic to polymerise on the part, then removing it and measuring thickness variations wherever necessary prior to bonding the coating on to the structure. Usually, however, thickness variations are less than 3 per cent, even for structures containing compound curvature areas, so measurements are only necessary if accuracies better than 3 per cent are required.

The addition of the plastic coating to a structure has a reinforcing effect. In any two-dimensional stress system, the correction factor to compensate for this reinforcement is given by

$$C = 1 \div \frac{S_p E_p}{S_m E_m}$$

where: S_p = cross-sectional area of plastic
S_m = cross-sectional area of metal
E_p = Modulus of elasticity of plastic
E_m = Modulus of elasticity of metal

In most practical cases this correction factor is small and may safely be neglected.

When bending effects in a plane perpendicular to the coating are present, reinforcement can be a more serious factor due to strain gradient effects in the plastic and alteration of the neutral axis position. In this case, correction factors can be obtained from correction curves similar to those shown in Fig. 16. Corresponding curves exist for most common structural materials[23].

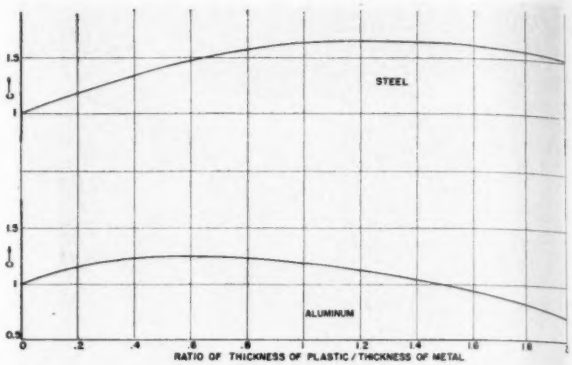

FIGURE 16. Corrections for bending C-factor by which the K factor of plastic should be multiplied.

8. Conclusions

The photoelastic coating technique has, over the past few years, reached a stage of development where it must be considered a major stress analysis tool, along with conventional photoelasticity, strain gauges and brittle lacquer techniques[24].

Its principle advantage over other techniques lies in its ability to provide quick surveys of large regions and subsequent accurate measurements at points of interest. Shear strain measurements can be made in both the elastic and plastic ranges of deformation. Any areas of local yielding are readily observed, even if readings are not possible during loading, as they will produce a permanent fringe pattern in the coating that will be seen when the structure is unloaded.

The photoelastic coating technique represents a major step forward in photoelastic development in that it allows stresses to be determined directly on the structure rather than by the previous method of plastic model analogy.

The difficulties encountered by previous investigators in obtaining coatings free from residual stresses, and the limitations of coatings that were applicable only to flat surfaces have finally been overcome, enabling extremely complex shapes to be covered with coatings completely free of residual stresses.

The advantage of Photostress over strain gauge techniques is that the strains are quantitatively determined in a continuous manner over every part of the coated structure, instead of only at the points at which gauges have been placed. The technique has shown itself to be suitable for direct industrial use, rather than being purely laboratory-limited. Application of plastic, and use of the associated instruments may safely be handled by suitably instructed technicians, although, as with any stress analysis technique, data reduction and interpretation should be in the hands of a competent engineer who is familiar with the limitations of the particular system being used.

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Space-Correlations in the Fluctuating Pressure Field Near to a Jet Engine

BY

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1. Introduction

An aspect of structural design which is becoming increasingly more important is the behaviour of a structure when it is subjected to random pressure loading. Random pressure fields can be encountered in several different ways, two of the principal sources of such fields being the noise emitted by a jet, and the fluctuating pressures in a turbulent boundary layer. Many jet-propelled aircraft have suffered secondary structure fatigue failures in those parts of their structures near to the jet stream, and it is not unlikely that certain failures of panelling in engine intakes have arisen because of vibrations set up by the turbulent pressure fluctuations in the boundary layers at the walls. Both problems are likely to become more urgent as aircraft and missile speeds and engine powers increase, and it is important that designers should know whether or not undesirable vibrations are likely to occur in a given design. It is therefore necessary to be able to make some estimate of the loads to which a structure in a random pressure field will be subjected, and consequently to be able to describe the random pressure field.

In this paper the problem is discussed in a general manner and attention is drawn to two simple types of random pressure field. An experiment is then described which suggests that one of these simple fields may serve as an approximation to the pressure field near to a jet.

2. General Discussion

2.1. DESCRIPTION OF PRESSURE FIELDS

To date, most of the experiments performed in connection with the problem of structural vibrations excited by random pressure fields have involved the measurement of the root-mean-square (r.m.s.) of the fluctuating pressure at various points in the field and the analysis of this information into r.m.s. levels in restricted frequency bands. Although such measurements are obviously important, they are insufficient for the solution of the problem. This is easily demonstrated by considering simple acoustic fields.

Fig. 1 shows two sound fields acting on a piston of area A mounted in an infinite baffle; in both cases the sound field consists of plane, simple-harmonic waves of r.m.s. amplitude p^* and frequency f. If the measurements described above are carried out the results will be the same in both cases, namely, it will be found that all over the surface of the piston the r.m.s. pressure is p^* and analysis will show that the frequency at which the pressure fluctuates is f. But the generalised forces on the piston in the two cases are clearly different, for whereas at any instant the pressure in (*a*) is uniformly distributed over the piston, in (*b*) it varies from point to point. Evidently some further measurement is required which will describe the instantaneous variations of the pressure over the surface of the piston.

Ideally, if the generalised force on the piston is to be calculated then a definite description of the sound field is required, *i.e.* the pressure on the piston is required as a function of position and time, $p(\vec{x}, t)$†. If this were given, the generalised force could be calculated as a function of time:

$$L(t)=\int_A p(\vec{x}, t)\, d\vec{x} \quad . \quad . \quad . \quad (1)$$

To compare the generalised forces arising from different sound fields the mean square value of the generalised force could be used. This is

$$\overline{L^2(t)}=\overline{\left\{\int_A p(\vec{x}, t)\,.\,d\vec{x}\right\}^2}=\overline{\int_{A_2}\int_{A_1} p(\vec{x}_1, t)\,.\,p(\vec{x}_2, t)\,.\,d\vec{x}_1\,.\,d\vec{x}_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where the suffices 1 and 2 indicate separate integrations and the bar denotes a time average.

In cases such as those in Fig. 1 where the r.m.s. pressures at all points are identical, this can be re-written as:

$$\overline{L^2(t)}=p^{*2}\int_{A_2}\int_{A_1}\overline{\frac{p(\vec{x}_1, t)\,.\,p(\vec{x}_2, t)}{p^{*2}}}\,.\,d\vec{x}_1\,d\vec{x}_2 \quad . \quad (3)$$

which demonstrates that the quantity which influences the mean square generalised force is the space correlation coefficient

$$\rho(\vec{x}_1, \vec{x}_2)=\overline{\frac{p(\vec{x}_1, t)\,.\,p(\vec{x}_2, t)}{p^{*2}}} \quad . \quad . \quad (4)$$

This fact has been pointed out earlier by Powell in Ref. 1, but it is not a complete statement. In general it is not only the mean square value of the generalised force which is of interest, but also the way in which it varies with time. Up to this point it has been assumed that the time variation will be simple-harmonic, in which case the mean square value of the generalised force would be a sufficient description, but this fact may not be known directly. A convenient way of describing the time-variation of the generalised force is found when it is recalled that the mean square value, (equation 2), is

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†For the problems of Fig. 1 this would be of the form $p(\vec{x}, t)=P_0\cos(\omega t-k\vec{x})$

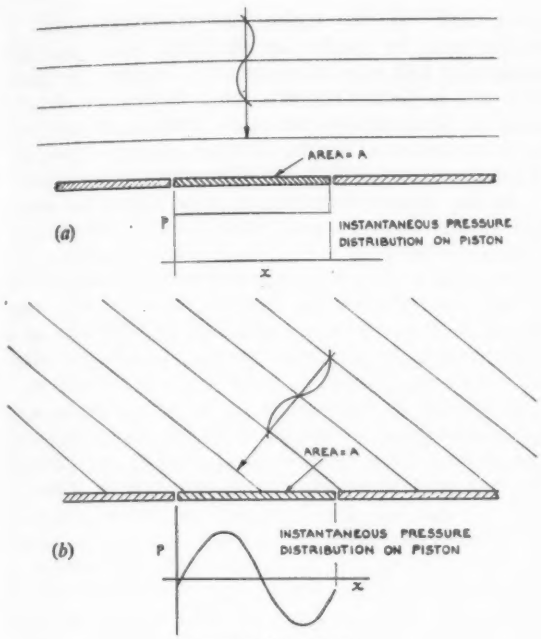


FIGURE 1 (*a*) and (*b*).

a special case of the auto-correlation of the generalised force†, which is:

$$\overline{L(t) \, . \, L(t+\tau)} = \overline{\int_{A_2}\int_{A_1} p(\vec{x_1}, t) \, . \, p(\vec{x_2}, t+\tau) \, . \, d\vec{x_1} \, d\vec{x_2}} \qquad (5)$$

From this expression it is clear that the basic measurement in the description of the pressure field is the space-time correlation of the pressures, the general definition of which is:

$$r(\vec{x_1}, \vec{x_2}; t_1, t_2) = \overline{p(\vec{x_1}, t_1) \, . \, p(\vec{x_2}, t_2)}. \qquad (6)$$

This argument has been developed by considering the information required for the calculation of the generalised force on a structure in a sound field. It should be pointed out, however, that the space-time correlation as defined in equation (6) gives a complete description of the sound field and is a fundamental quantity quite apart from its usefulness in the problem of the excitation of structural vibrations.

2.2. RANDOM PRESSURE FIELDS

In the previous section it was shown that the information required about a pressure field for the description of the generalised force acting on a structure is contained in the space-time correlation of the pressures in the field. Examination of this quantity, (eqn. (6)), shows that it is very complicated; in an extreme case it could depend upon both vectors $\vec{x_1}$ and $\vec{x_2}$ (each of which has three components) and the two times t_1 and t_2. The experimental work involved in its determination might be considerable and it is advisable to consider some simple models first, models which might serve as approximations to cases met in practice.

Consider then a one-dimensional problem, *e.g.* a beam with a distributed load which varies both with position on the beam and with time, and let the variations now be not simple-harmonic, but random. An almost essential assumption to be made is that the problem is stationary, that is that the average conditions (for example the mean square loading at a given point) do not vary with time. In this case the space-time correlation will not depend upon t_1 and t_2 separately but only on their difference $(t_2 - t_1)$, which will be denoted by τ. Further assume that the average conditions do not vary with position on the beam. In other words, the loading is homogeneous and, for example, the mean square loading is identical at all points. The space-time correlation will now depend only upon $(x_2 - x_1)$, or ξ. The space-time correlation coefficient may now be written:

$$\rho(\xi, \tau) = \frac{\overline{p(x, t) \, . \, p(x+\xi), (t+\tau)}}{p^{*2}}. \qquad (7)$$

A graph of the loading on the beam will be a curve, the ordinates of which vary randomly with time. If the behaviour of such a curve is considered it is possible to distinguish two extreme cases. These are:

(*i*) The ordinates of the curve vary randomly and almost independently of one another, the only restraining condition being that the curve remains continuous.

In this case the space-time correlation coefficient will for all values of $\tau > 0$ start at some value less than unity and fall to zero as ξ increases; the value at $\xi = 0$ will decrease to zero as τ increases.

(*ii*) The ordinates of the curve vary randomly with time but are dependent in that the values assumed at ξ_1 at times t_1, t_2, t_3, etc. are assumed at ξ_2 at times $t_1 + \tau_1$, $t_2 + \tau_1$, $t_3 + \tau_1$ . . . etc.

Now the space-time correlation is a set of similar curves displaced equal distances for equal increments in τ (*see* Fig. 2(*b*)).

In the first of these two cases the pressure is a random function of both space and time, *i.e.* it is of the form $p(x, t)$ where the fluctuations of p with x and t are almost independent. The second is different in that although the pressure is again a random function of space and time the fluctuations with x and t are now dependent, *i.e.* the pressure is a function of $(x - ct)$.

It is with the second case that the present work is concerned. Physically the situation is one in which a fixed pattern of loading moves across the beam at a constant speed. It is one which would obtain if the beam were mounted in an infinite baffle on to which plane waves of sound of random amplitude were incident; it would also be approximated to if a turbulent fluid flowed down the beam, provided that the assumption is made that the frequency of the fluctuations within an eddy in the boundary layer is low enough for no change to have taken place during the time the eddy takes to travel the length of the beam.

†The fact that the auto-correlation describes the time-variation is clear from its relation to the power spectrum.

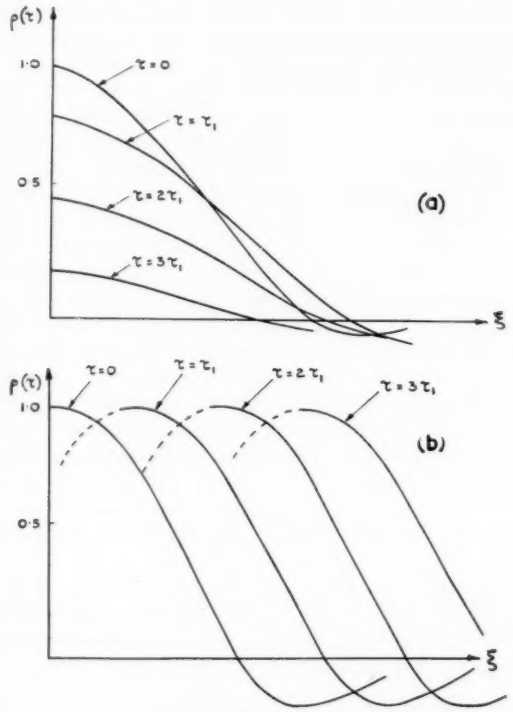


FIGURE 2 (*a* and *b*).

2.3. PRESSURE FIELD AROUND A JET ENGINE

It is now well known that a jet of air generates sound independently of the machinery which produces the jet and as a result of the work of Lighthill[2, 3] the mechanism by which this sound is generated is understood. As soon as a jet of air leaves an orifice a boundary layer, which rapidly becomes turbulent, begins to grow at the edge of the jet and diffuses into the jet causing it to spread. At about 4½ diameters from the exit, the inner edges of the boundary layer meet at the centre of the jet and thereafter the velocity on the centre line begins to fall and the angle of spread increases. The sound which is heard has its origin in the turbulence, first in the free boundary layer and then, from the 4½ diameter point onwards, throughout the jet. The turbulence, and so the sound generated, is random; if the signal from a transducer is displayed on a cathode-ray oscilloscope screen it is quite irregular and shows no sign of discrete frequency components. A considerable amount of attention has been given to the sound fields around jets and much data have been amassed, though as mentioned above these have been concerned in the main with mean square levels.

The jet is found to be a distributed source of sound; recent research indicates that the majority of the sound radiated away from the jet is generated in the first ten diameters. At large distances, *i.e.* at distances great enough for the jet to be regarded roughly as a point source, the sound field consists of spherical waves, the intensity of which varies with angular position, (being greatest at acute angles to the jet direction) and decreases along a given radius according to the inverse square law. In this region the waves may, over a limited area, be treated as effectively plane and the sound field will have characteristics roughly like those dealt with in Section 2.2 (*ii*). This, however, is of little practical significance so far as the problem of structural failure is concerned for the necessary distances from the jet are much larger than the dimensions of an aircraft.

As the distance from the jet is decreased the sound field at first becomes progressively more complicated; at distances between 5-30 diameters from the boundary the sound at a point is contributed to by all parts of the jet and since the jet can therefore no longer be considered at a point source but has to be taken as a distribution of sources, the waves are no longer plane and cannot be regarded as going in a single direction.

If the jet is approached even more closely, it is noticed that the mean square of the fluctuating pressures rises rapidly; very close to the boundary, at distances less than two diameters, it rises very rapidly indeed[4]. This is due to the fact that at these distances the transducer begins to measure the actual hydrodynamic fluctuations associated with the eddies in the turbulence of the jet. These fluctuations fall off rapidly with distance from an eddy and so it seems likely that the major part of the signal from a transducer in such a position arises from the effect of local eddies and that only a small part is due to sound generated elsewhere. If this is so, it may be that an approximation can be made to the pressure field; in fact when it is recalled that the eddies in a jet will be washed downstream just as they are in a turbulent boundary layer it is seen that conditions may again approximate to those described in Section 2.2 (*ii*). This would be of considerable practical importance, for in many aircraft configurations the jet stream lies close to the fuselage or wing. A series of experiments made to examine this hypothesis is described below.

2.4. BASIS OF EXPERIMENT

If a pressure field is convected without change then, the pressure being a function of $(x-ct)$ where c is the convection velocity, a separation of two microphones is equivalent to the introduction of a time delay between the signals from two microphones at the same point. Thus a space correlation should be similar to an autocorrelation, the only difference being one of abscissa scale. In the absence of a time delay unit, the autocorrelation can be calculated from the power spectrum* which is easily derived from spectrometer measurements. If then the delay time is multiplied by c to give $\xi=c\tau$, an equivalent separation, the resulting curve should match the measured space-correlation curve.

3. Description of Experiment

The experiments to be described were carried out using the port outer engine of Comet G-ALYS, an aircraft available at the R.A.E. for noise research. Since only a short time was available, the scope of the work was kept very simple.

Measurements were taken in the horizontal plane

*See Appendix.

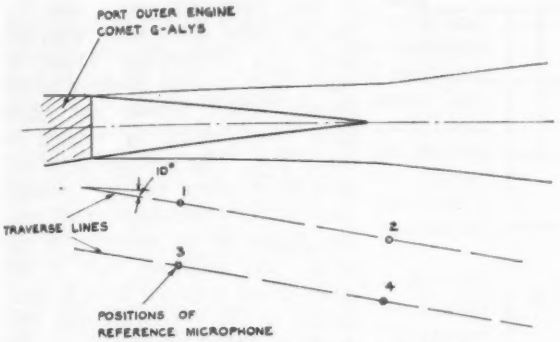


FIGURE 3. Details of measuring stations.

through the centre of the jet along two traverse lines parallel to, and one and two diameters from, a reference line struck from the centre of the jet exit at 10° to the direction of the jet (*see Fig.* 3). Four positions were chosen for the reference microphone, two on each traverse line at two and five diameters from the jet exit plane. The reference microphone was placed at each of these positions in turn and the second microphone traversed past it in the upstream and downstream directions. The jet speed was kept low (about 710 f.p.s.) for several reasons, but mainly to reduce annoyance and to keep the speed of the jet below the speed of sound in the surrounding atmosphere†.

Two Bruel and Kjaer condenser microphones were used, each with its diaphragm in the horizontal plane. The microphone signals were amplified and then passed to a computer consisting of a quarter-squares multiplier‡, using a biassed-dioded function generator‡, an integrator‡, and a timing circuit used to switch off the integrator after roughly 5, 10 or 15 seconds. The result of a measurement appeared on a meter. The computer was fitted with switches in the input leads so that its two channels could be connected either one to each microphone or both to either microphone. The procedure at each separation of the two microphones was to integrate over the chosen interval of time the square of the signal from one microphone, the square of the signal from the other, and then the product of the two signals. From this the correlation coefficient could easily be calculated with a slide rule.

For each of the four positions of the reference microphone readings were taken, with a Bruel and Kjaer spectrometer and level recorder, of the spectrum of the noise at three points; these were the reference point and the upstream and downstream points at which the space-correlation first became zero.

4. Results

The results of the four correlation traverses are given in Fig. 4. In calculating the correlation coefficient for these curves the average value of the product of the two microphone signals has been divided by the product of their r.m.s. values (the mean square of each signal having been computed for the same integration time as the product). The shapes of the curves are regular and, except for the positive half of the curve for position 2, are roughly as one would expect. The oscillations

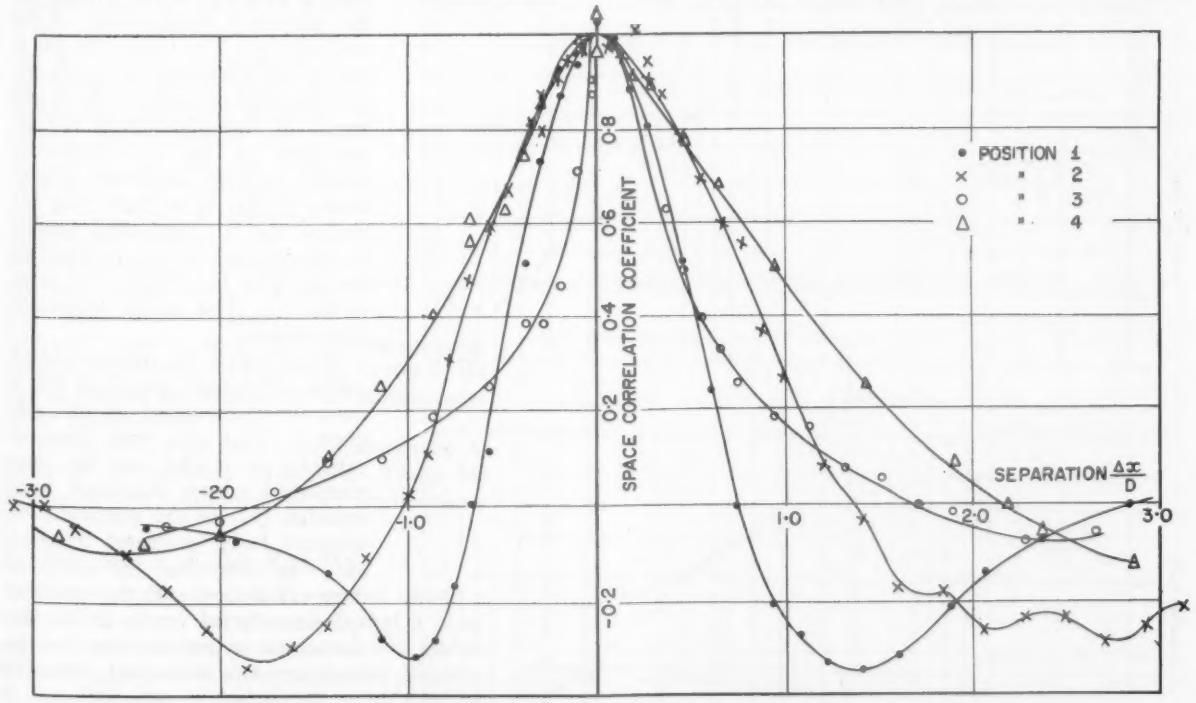
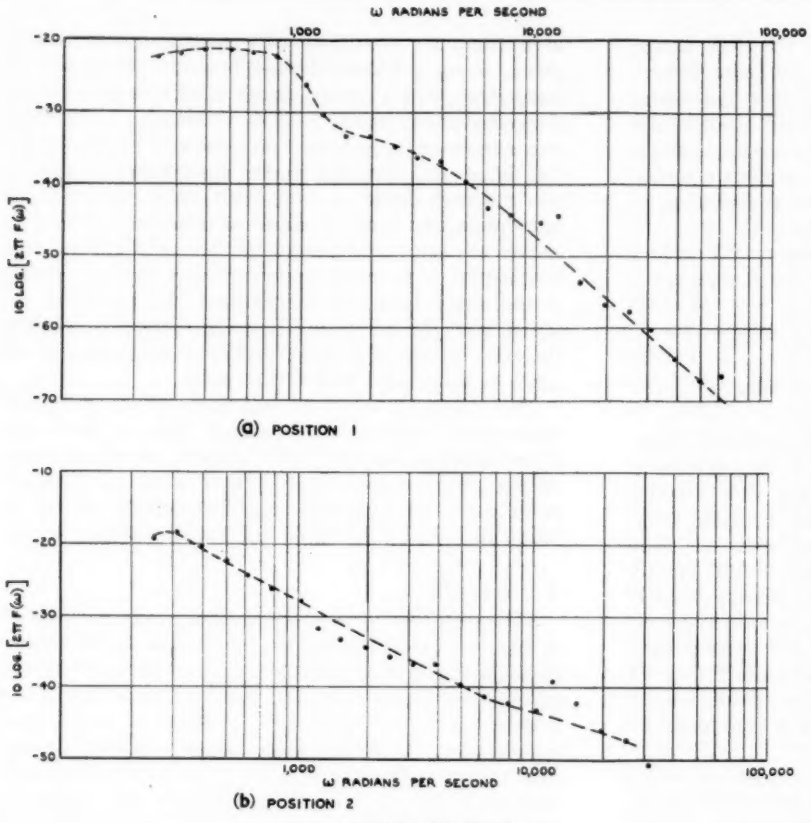


FIGURE 4.

†Certain curious effects are noticed when the jet speed rises above 1100-1200 f.p.s. *See* R.A.E. noise reports.

‡For circuit details of these *see* Ref. 5.



in this particular curve may be due to some effect other than jet noise (*e.g.* compressor whine, of which there is some evidence in the spectra which follow) but much more work would be needed to check this. The broadening of the correlation curve as the reference point moves downstream arises from the change in the spectrum of the noise, and indicates that in the downstream positions there is more energy in the low frequencies than in the upstream positions.

Figure 5 (*a*)-(*d*) show the power spectra in dB. of the microphone signals at the four reference positions. These results have been plotted as the logarithm of the power spectral density since this is the form in which they are required for the present work. The power spectral density was originally calculated as a function of the frequency f, but later in calculations it was more convenient to work in terms of the circular frequency, ω. Rather than recalculate the power spectral density, it has merely been plotted as $2\pi \cdot F(\omega)$ instead of $F(\omega)$. It is important to note that these spectra have not been corrected for the frequency characteristic of the microphone. The reason for this is that in the correlation measurements the computer operates on the output signal of the microphone and its amplifier, *i.e.* on the uncorrected signal. Another important point to notice is that it is clear from the spectra that a considerable amount of information is lost because the spectrometer has filters only down to 40 c.p.s. This will be referred to again below.

To calculate the auto-correlation curves, the power spectra of Fig. 5 must be extrapolated to zero frequency. This has been done as carefully as possible and the auto-correlation curves calculated using equation (11) of the appendix, the integrals being evaluated numerically. In comparing the results of these calculations with the measured space-correlation curves to test the convection hypothesis, one has to select a convection speed. There is

FIGURES 5 (*a*, *b*, *c* and *d*). Power spectra at reference microphone.

little to guide one in this choice and so it was assumed that the eddies in the free boundary layer of the jet move at roughly half the local speed of the jet as measured at the centre line, this being drawn from the crude physical picture of eddies acting as rollers between the central part of the jet and the surrounding air. Using this assumption, the abscissae of the auto-correlation curves were scaled to equivalent separations to get space-correlation curves.

Figure 6 shows the comparison between the measured space-correlation curve and the scaled auto-correlation curve for position 1. The agreement is good, particularly for the negative half of the curve (which is upstream from the reference point). The results for position 2 are shown in Fig. 7. Here the results are not quite so good, but if this is compared with Fig. 6 an interesting point emerges. In the negative half of Fig. 6 the zero-crossings of both curves coincide, indicating that the convection velocity is exactly 0·5 times the jet speed. In the positive half the indication is that the convection speed is greater than this and strength is given to this by Fig. 7 which shows that further downstream the difference in the zero-crossings increases.

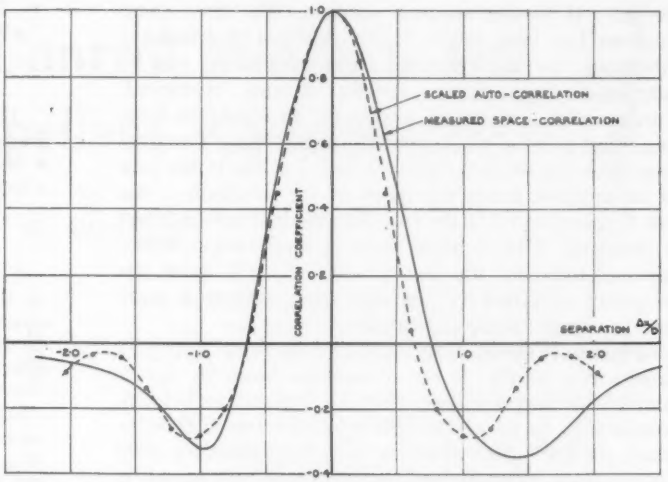


FIGURE 6. Comparison of measured space-correlation and scaled auto-correlation. Position 1.

There is, however, an alternative reason for the discrepancies of Fig. 7. The power spectrum used for the calculation in this case is that shown in Fig. 5(*b*) and if this is examined it will be seen that the extrapolation to zero frequency is rather difficult. Because of the shift of the power spectrum to lower frequencies, the low-frequency part of the spectrum represents a considerable fraction of the whole and the shape assumed for the curve below 40 c.p.s. affects the auto-correlation curve for values of τ roughly up to the first zero-crossing. Thus the discrepancy of Fig. 7 may be due to the loss of information because of the limited range of the spectrometer.

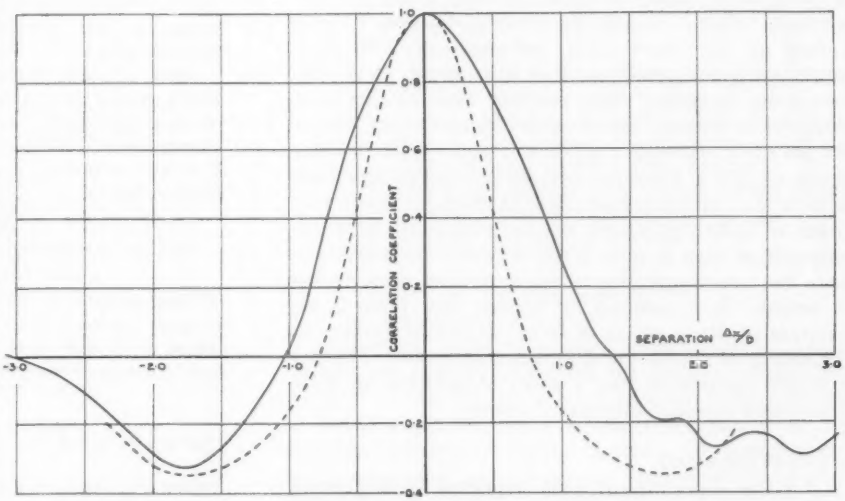


FIGURE 7. Comparison of measured space-correlation and scaled auto-correlation. Position 2.

The results for position 3 are shown in Fig. 8. There is no apparent agreement. Those for position 4 were similar and so are omitted here.

5. Discussion of the Results

From the tentative work reported above it seems likely (from Figs 6 and 7) that a good approximation to the space correlation curves along lines parallel to and roughly one diameter or less from the boundary of a jet may be obtained by scaling auto-correlation curves on the assumption that eddies in the jet are convected at about half the speed on the centre line of

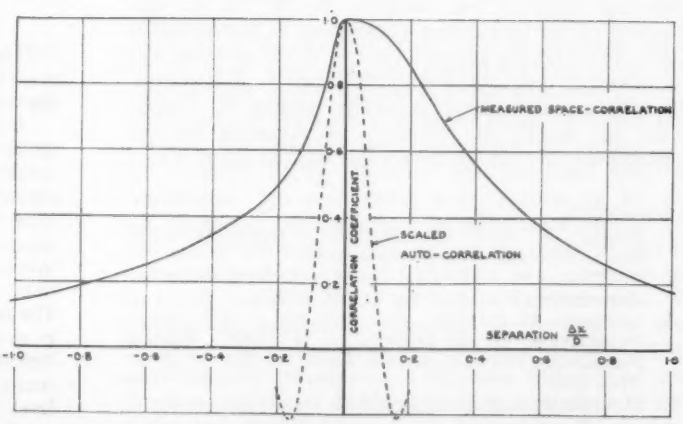


FIGURE 8. Comparison of measured space correlation and scaled auto-correlation. Position 3.

the jet. If further research confirms this, then some progress has been made in the problem of structural vibrations, for the necessary auto-correlations can be calculated from power spectra already measured. Further work is obviously necessary. Probably the most important point to be checked is whether the poor agreement between the two curves in Fig. 7 is due to the lack of information about the shape of the spectrum in the low frequencies or to the fact that the convection speed is changing. This could be done by model experiments, because reducing the size of the jet will raise the frequency spectrum of the noise and so bring it more into the range of the instruments.*

Figure 8 shows that the method will not give satisfactory results at two diameters from the jet; a simple calculation shows that the convection velocity would need to be about 5000 f.p.s. for the method to work. At first sight this seems to be ridiculous, for 5000 f.p.s. is very different from the jet speed. However, if a space-correlation curve is taken in a field of plane sound waves along a line at an angle α to the direction of travel of the waves, the trace velocity along this line is $c/\cos\alpha$, where c is now the velocity of sound. In such a field as this "convection" velocities of 5000 f.p.s. would be quite possible. For this reason it is very tentatively suggested that another useful experiment would be to measure the space-correlation along lines at several angles through a given reference point, in other words to plot a polar diagram of the space-correlation relative to a reference point such as point 3. If the mechanism of eddy convection has been replaced by wave-propagation then at some angle it should be possible to scale the auto-correlation using a velocity near to that of sound. It is realised, of course, that there is no question of plane waves of sound at points so close to the source of sound, (as mentioned in Section 2.3), but it is still considered that a short experiment on these lines could produce interesting results.

ACKNOWLEDGMENTS

All the experimental work reported in this paper was carried out by Mr. C. W. Skingle and Sqn. Ldr. J. Anstess at the R.A.E. The circuitry for many of the computer elements was designed by Mr. K. R. McLachlan of the Electronics Laboratory at Southampton University, and the author's interest in the problem was stimulated and encouraged by Professor E. J. Richards. To all these the author gratefully tenders his thanks. Also, he thanks the Ministry of Aviation for the opportunity of working for a short time at the R.A.E.

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*Such experiments, carried out after the work discussed in this paper, are reported in Ref. 6.

APPENDIX

If we have a random function $f(t)$, then its average properties may be described in terms of the average power it dissipates at each circular frequency. Thus a function $w(\omega)$ is defined such that

$$\overline{f^2(t)} = \int_0^\infty w(\omega) \, . \, d\omega, \quad . \quad . \quad . \quad (8)$$

i.e. the total average power (or the mean square value) is equal to the sum of the powers developed at all frequencies. The function $w(\omega)$ is known as the power spectral density, or power spectrum. Now

$$\overline{f^2(t)} = \lim_{T\to\infty} \frac{1}{T} \int_0^T f^2(t) \, . \, dt$$

and this is a particular case of another function

$$r(\tau) = \overline{f(t) \, . \, f(t+\tau)} = \lim_{T\to\infty} \frac{1}{T} \int_0^T f(t) \, . \, f(t+\tau) \, . \, dt \quad (9)$$

known as the auto-correlation function of the random function $f(t)$.

Both of these functions are descriptions of the way in which, on the average, $f(t)$ varies with time; $w(\omega)$ in terms of equivalent sinusoidal components, $r(\tau)$ in terms of the changes which take place in $f(t)$ over an interval of time τ. It is not surprising therefore that they are related. This relationship is:

$$r(\tau) = \int_0^\infty w(\omega) \, . \cos \, . \, \omega\tau \, . \, d\omega. \quad . \quad . \quad (10)$$

The value of $r(\tau)$ at $\tau=0$ is $\overline{f^2(t)}$. In many instances it is more convenient to deal with a function the value of which at $\tau=0$ is unity. This is called the auto-correlation coefficient and, using this, equation (10) is replaced by:

$$\rho(\tau) = \int_0^\infty F(\omega) \, . \cos \omega\tau \, . \, d\omega. \quad . \quad . \quad (11)$$

where $F(\omega)$ is the normalised power spectral density and is such that

$$\int_0^\infty F(\omega) \, . \, d\omega = 1. \quad . \quad . \quad . \quad (12)$$

The calculations for this paper were made using equation (11), the integration having been done numerically. For the calculations, the function $F(\omega)$ is found as follows:

By means of the Bruel and Kjaer $\frac{1}{3}$rd-octave spectrometer a spectrum of the signal in dB. relative to some arbitrary level is obtained. This spectrum has to be corrected to allow for the gradual increase in the filter bandwidth as the frequency is increased and, if it is assumed that the spectrum is flat over the frequency interval covered by a filter, the correction may be shown to be $-10 \log . \Delta f$, where Δf is the bandwidth of the filter. The resulting curve, which is in dB. per (cycle per second), is now integrated by calculating the sum of the anti-logarithms of the readings and taking the logarithm of the sum to get the total power P dB. relative to some arbitrary level. The "fractional power" is then calculated by subtracting P from each reading and taking the anti-logarithms. The result is an approximation to $F(\omega)$.

Some Thrust Control Methods For Solid Propellant Rockets

BY

K. W. PEARCE

1. Introduction

Solid propellant rockets are now being used in vehicles whose flight paths are mostly outside the atmosphere and need close control. Engines for such vehicles must not simply provide accelerating thrust but should also be capable of having the direction, magnitude and duration of this thrust altered at will. Some devices and methods for accomplishing such control have been described elsewhere, *see* Refs. 1, 2, 3 and 4. I shall attempt both to discuss these in more detail and to introduce others which I believe have not yet been mentioned.

NOTATION

- A_B effective cross sectional area of bellows
- A_c internal cross sectional area of motor chamber
- A_t throat area of motor nozzle
- A_v enlarged throat area after nozzle severance
- a_v total area of radially facing venting holes
- C the moment applied to pressurised bellows
- C_F thrust coefficient of motor nozzle
- C_F' thrust coefficient of radially facing venting nozzle
- C_{Fr} thrust coefficient of severed nozzle
- D internal diameter of motor case
- d throat diameter of motor nozzle
- F motor thrust
- $\dot{F}$ peak thrust produced on severing motor nozzle
- F_r reduced thrust
- g_c conversion factor from lb. to slugs (equals 32·2)
- I specific impulse of propellant
- I_T total impulse of separating motors
- I_r specific impulse of propellant during the reduced thrust stage
- J the thrust to weight ratio of the weapon motor at launch
- K the ratio of the thrust of the separating motors to the thrust of the weapon motor
- k_ϕ the ratio of applied moment to the rotation of one end of the unpressurised bellows with respect to the other
- L length of motor chamber
- l length of bellows
- M motor weight
- M_0 motor weight at launch
- m_e equivalent fixed weight of nozzle cooling water
- m_p total weight of propellant in motor
- m_s structural weight of motor
- m_w weight of nozzle cooling water
- N_D discharge coefficient in propellant burning rate equation
- n exponent in propellant burning rate equation
- P motor burning pressure
- P_r motor burning pressure after thrust reduction
- q_E buckling pressure of clamped bellows
- V_r ratio of venting area to original nozzle throat area
- X_p distance of bellows pivot point, from movable end of bellows
- Y separation distance
- α the angle of inclination of the radial venting holes to the axis of the motor
- β ratio of the weapon motor weight at separation to the weapon motor weight at launch
- λ the structural factor for the weapon
- θ the angle between the line of action of the separating thrust and the weapon axis
- ϕ angle of rotation of bellows

2. Control of Thrust Duration

2.1. INTERRUPTION OF BURNING

A burning solid propellant charge can be extinguished by suddenly releasing the pressure within the motor[5]. Probably the simplest pressure venting device is one in which the motor nozzle is detached from the chamber causing a sudden increase in throat area. Such a device is likely to cause a peak thrust soon after the nozzle is detached and with the aid of Figs. 1 and 2 we shall attempt crudely to describe this thrust peak.

The thrust of a rocket may be regarded as the difference between two forces: the gas pressure at the head end of the chamber acting over the projected area of the head end, and the longitudinal stress in the chamber wall acting over the chamber wall cross section. At the instant the nozzle separates from the rocket the strain in the chamber wall, and hence the stress, and the pressure at the front of the chamber, will be unchanged. No peak thrust will therefore be felt by the vehicle at this instant. Detachment of the nozzle will reduce the longitudinal pull on the chamber and it will start to relax. As the chamber is constructed of an elastic material it will perform a damped series of longitudinal oscillations, causing the tension in the chamber wall at the front to fluctuate with time. The amplitudes of consecutive oscillations will depend on the damping effects of the remaining propellant in the motor and their frequency will depend on the dimensions of the chamber and the speed of sound in the

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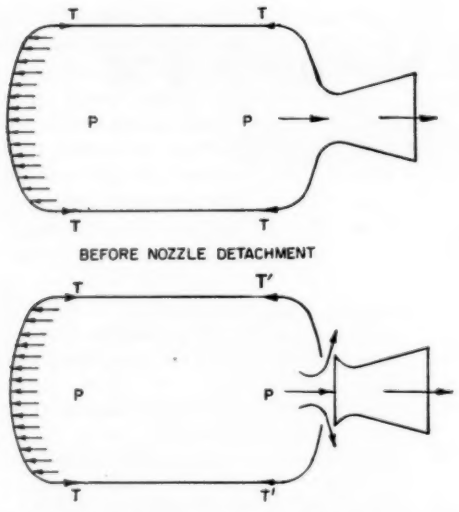


FIGURE 1. Axial venting of a solid propellant rocket.

chamber material. Until the expansion wave moving through the propellant gases from the nozzle end of the rocket reaches the front of the chamber the pressure there will not decline, and when it does the decline may be smooth or oscillatory. By considering the combined effects of chamber wall tension and chamber pressure immediately after nozzle severance we can estimate the thrust peak.

It will be assumed, when making the estimate, that the pressure in the motor chamber remains unchanged at least for the time taken by the motor chamber to oscillate once. If the thrust coefficient of the nozzle is taken to be 1·7 then before interruption the thrust was

$$F = 1{\cdot}7 A_t P \quad . \quad . \quad . \quad (1)$$

where A_t is the nozzle throat area and P the motor chamber pressure.

In a motor chamber of cross-sectional area A_c this thrust may be regarded as the difference between two forces: the pressure force acting over the front end, PA_c, and the tension in the chamber wall, $P(A_c - 1{\cdot}7A_t)$. After severing the nozzle the thrust coefficient of the motor will probably fall to about 1·25 and so the pull on the chamber will be reduced by $P(1{\cdot}25A_v - 1{\cdot}7A_t)$ where A_v is the enlarged throat area. An elastic wave will then be propagated forward along the chamber wall and when it reaches the head end the thrust experienced by the vehicle will start to rise swiftly. If the elastic wave is heavily damped then there will be little "overswing," the chamber wall tension will fall and the thrust will rise by a maximum amount of

$$P(1{\cdot}25A_v - 1{\cdot}7A_t)$$

However, if there is little damping of the oscillations in the chamber wall then there will be nearly a complete "overswing," the tension in the chamber wall will fall and the thrust will rise by twice the previous amount, namely

$$2P(1{\cdot}25A_v - 1{\cdot}7A_t)$$

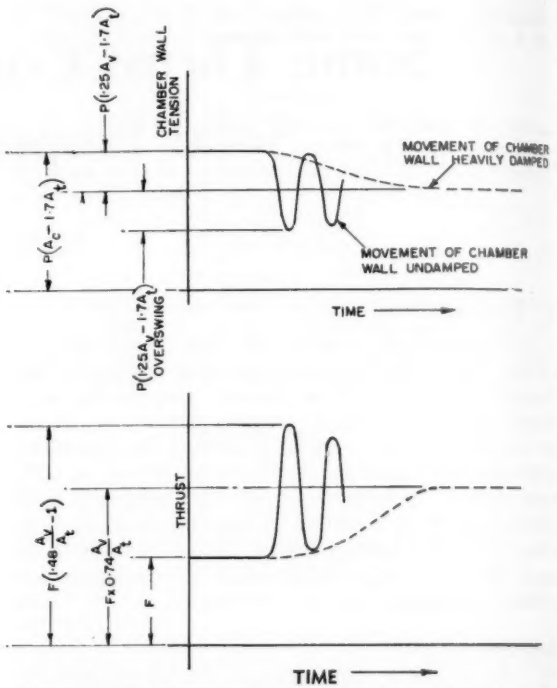


FIGURE 2. The thrust peak caused by the axial venting of a solid propellant motor.

The shape of the thrust peak suggested by this argument is shown pictorially in Fig. 2 and the magnitude will lie between the following two values: —

$$\hat{F} = F\left(0{\cdot}74\frac{A_v}{A_t}\right) \quad . \quad . \quad . \quad (2)$$

and

$$\hat{F} = F\left(1{\cdot}48\frac{A_v}{A_t} - 1\right) \quad . \quad . \quad (3)$$

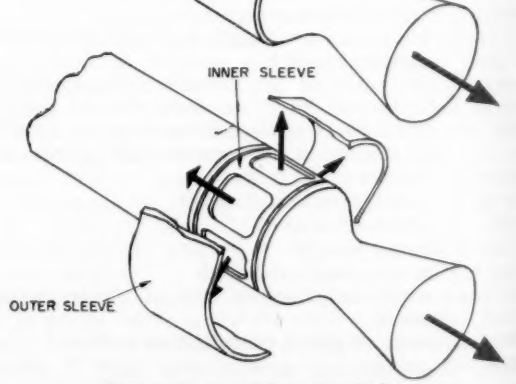


FIGURE 3. A radial venting device.

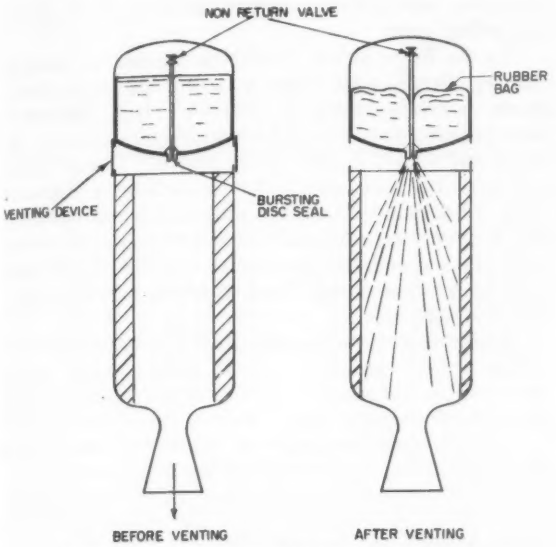


FIGURE 4. Water injection to prevent re-ignition.

With simple arguments it is difficult to say what happens at a later stage in the venting process. It is conceivable that the thrust peak could be even bigger than has been described so far if the pressure at the rear end of the chamber were to fall so quickly, after the nozzle had been severed, that the axial pull on the chamber would fall to nothing, while the pressure at the front of the chamber would remain comparatively high.

Although the thrust peak may seem frightening it is so brief that the vehicle structure could exert a considerable attenuating effect on it and a simple shock absorber system could do much better. A thrust peak can be avoided if venting is accomplished through a number of equally sized and spaced radial holes, as depicted in Fig. 3. However, care must be taken to ensure that the combined area of the venting holes and the rocket nozzle throat is still much less than the cross-sectional area of the motor chamber, otherwise there will be a big axial pressure drop within the chamber and a thrust peak will appear.

A simple radial venting interrupter, like the one shown in Fig. 3, consists of two concentric sleeves. The inner one has two circumferential grooves in its outer surface for rubber ring seals and between these grooves are a number of equally spaced identical venting holes. All the venting holes are sealed by a single outer sleeve fitting snugly over the two rubber ring seals. Two grooves parallel to the axis of the motor are machined into the outer surface of the outer sleeve and filled with cutting explosive. If the amount of explosive and dimensions of these grooves are chosen judiciously, then upon detonating the explosive the outer sleeve will be cut in two, without damaging the rest of the motor, and all venting holes will be opened quickly and simultaneously.

When interrupted burning experiments have been done in ground firings the solid propellant grains have occasionally reignited and, because of the enlarged motor throat area, burned in an unsteady manner[6].

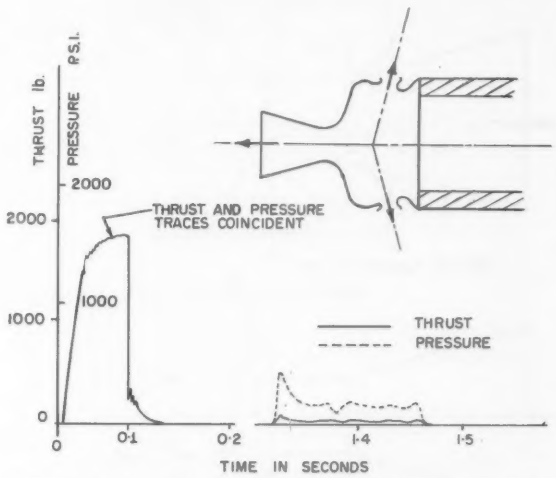


FIGURE 5. The "non self propulsive" radial venting device.

At first sight this tendency for reignition may be a serious drawback for any thrust cut-off system, but there are several reasons why reignition is not dangerous. First, for all but short range vehicles the motor is likely to be separated from the warhead soon after thrust cut-off. As the time to reignition is usually several seconds with internal burning charges there will be plenty of time to get the motor well clear of the rest of the vehicle so that no collision will take place if reignition does occur. Secondly, propellant ignition is more difficult at high than low altitudes and so reignition is less probable in a motor interrupted in flight than in one interrupted on the ground. Thirdly, a small quantity of water can be sprayed into the motor immediately after venting and an arrangement for doing this is illustrated in Fig. 4. A small tank containing water in a rubber bag is attached to the front of the motor. Above the bag there is an empty space connected to the motor chamber by a central insulated pipe and a non-return valve. An annular spray nozzle in the bottom of the tank is sealed by a backed-up bursting disc which will only burst into the motor. While the motor is burning the space over the rubber bag will be pressurised with propellant gas and suitable design precautions can be taken to ensure that the rubber bag will not be burned by these propellant gases. When the motor chamber is vented the pressure in it will fall to nothing, the bursting disc over the spray nozzle will rupture and the water will quickly be squeezed out of the bag into the motor chamber. A water injection system could only be afforded in a low performance vehicle, but this is just the vehicle in which it is most likely to be needed. Finally, a radial venting device can be designed with the venting holes facing slightly forward so that when gas discharges through them they generate sufficient thrust to balance the main motor nozzle. A sketch of a radial venting device which is not self-propulsive, together with a thrust and pressure versus time record of an interruption and reignition is given in Fig. 5. The rocket used for this experiment contained a three inch diameter internal and

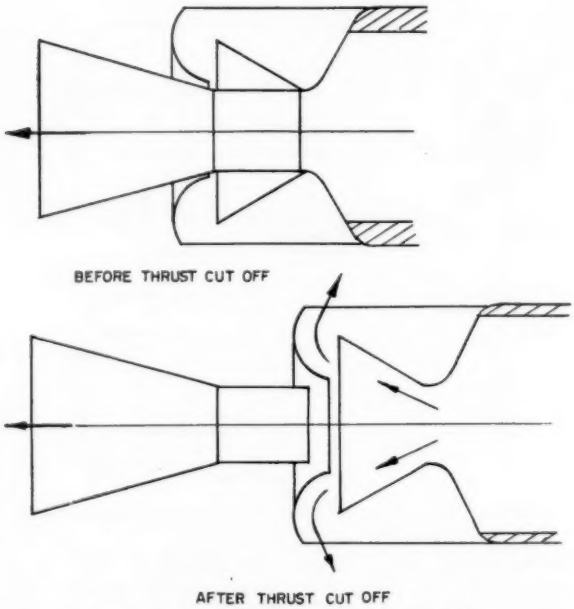


FIGURE 6. A spoiler plate thrust cut-off device.

external burning tubular cordite charge which reignited quickly and often. Although this venting device is not quite *non-self-propulsive*, the propulsive effect of re-ignition has been considerably reduced and could be eliminated with further experiments. Thrust cut-off with such a venting device is likely to be as nearly instantaneous as is possible.

2.2. THRUST SPOILING

One spoiler configuration which might be adapted to solid propellant motors has already been described[7]. Another device is sketched in Fig. 6; it consists of a nozzle with two expansion cones: the front one has a wide divergence half-angle of 30° and the rear one a more conventional divergence half-angle of 15° and a short parallel throat section.

Between the two cones and around the throat section of the rear one there is an annular spoiler plate. When thrust cut-off is needed the rear cone with its short throat section is detached and the exhaust gases flow through the front cone on to the spoiler plate and no more thrust is produced.

The front cone is introduced to control the flow of gases on to the spoiler plate so that the system will operate in a way which is independent of altitude, *i.e.* independent of the ratio: motor pressure/local atmospheric pressure. If the front cone were omitted then, as the altitude of operation increased, the jet would spread more and more and a higher proportion of gas discharged from the rocket would impinge on the spoiler plate, causing the reversed thrust component to increase.

To keep the size and weight of the device to a minimum the divergence half-angle of the front cone should be as wide as possible, but if it is made too wide the jet will separate from the wall of the cone and the front cone will cease to control the flow of gas on to the spoiler plate.

To see if the device would be affected by altitude changes, firings were done at motor pressure/atmospheric pressure ratios of 500/14·7 and 3000/14·7. Such pressure ratios would correspond to altitudes of, say, 0 and 42,000 ft. for a given rocket. Typical thrust and pressure time curves for a three-inch diameter rocket fitted with the spoiler plate device are shown in Fig. 7. With the rear cone absent, there was no thrust when the motor burning pressure was 500 lb./in.² and only 0·8 per cent of full thrust when the motor pressure was 3000 lb./in.².

It might be possible with sufficient experiments to devise a fixed geometry spoiler plate system whose behaviour is independent of the motor pressure/local atmospheric pressure ratio. Even if this is not possible it would be a simple matter to incorporate some small retractable vanes that could be used to remove the last fraction of thrust not cancelled by the fixed spoiler plate.

2.3. FORCIBLE SEPARATION

The acceleration of a ballistic missile warhead may be stopped by forcibly separating the burning solid propellant motor from the warhead. The technique is to give the burning motor a short strong push backwards and sideways so that it first disengages from the warhead and then overtakes the warhead on a parallel course.

A sketch of the force system selected for study is given in Fig. 8. This arrangement was examined because it was simple to analyse and gave results which were typical of this technique of stopping warhead acceleration. The weapon motor is separated from its

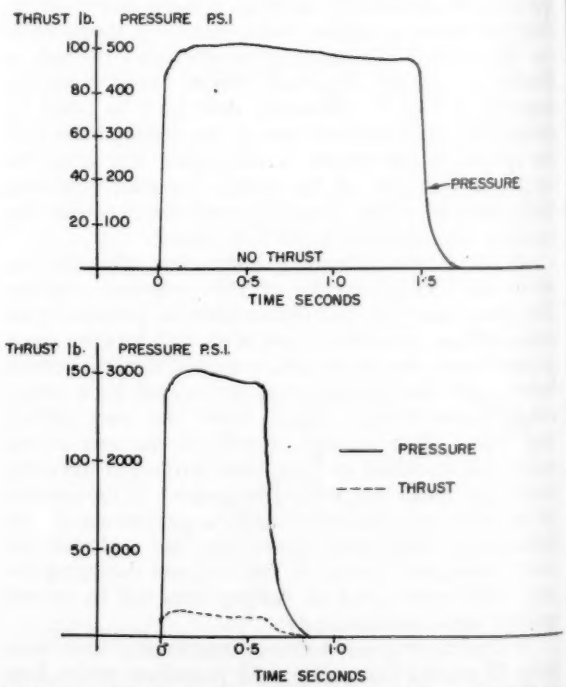


FIGURE 7. Firing record of a rocket fitted with a spoiler plate (rear cone absent).

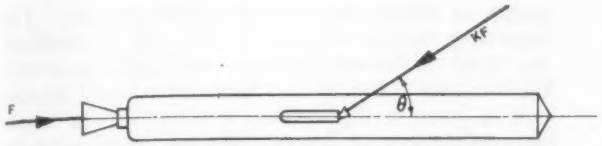


FIGURE 8. Forces acting on the weapon motor during the early stages of separation.

warhead by firing sets of motors inclined at an angle to the weapon motor axis. As shown, all thrusts pass through the centre of gravity of the weapon motor.

A simplified mathematical analysis of the separation path* traced out by the burning weapon engine, which is illustrated in Fig. 9, provides the following equation:

$$\frac{YMF}{I_T^2 g_c} = \sin\theta \left\{ \cos\theta + \frac{\sqrt{[(K\cos\theta - 1) + (K\cos\theta - 1)^2]}}{K^2} - \frac{1}{2K} \right\} \quad (4)$$

where Y the separation distance in feet (*see* Fig. 9)
F the forward thrust of the weapon motor in lb. force
K the ratio of the thrust of the separating motors to the forward thrust of the weapon motor
$\frac{M}{g_c}$ the weight of the weapon motor and separating motors at the instant of separation in slugs
I_T the impulse of the separating motors in lb. sec.

The right hand side of equation (4) is a function solely of the dimensionless quantities which characterise the separating system, namely the ratio of separating motors thrust/weapon motor thrust, K, and the angle between the separating thrust line and the weapon motor axis, θ. The left hand side of the equation is a dimensionless group which indicates the performance of the separating system because it contains the ratio Y/I_T^2 and if we are to get the best from the separating motors the quantities K and θ must be selected to give

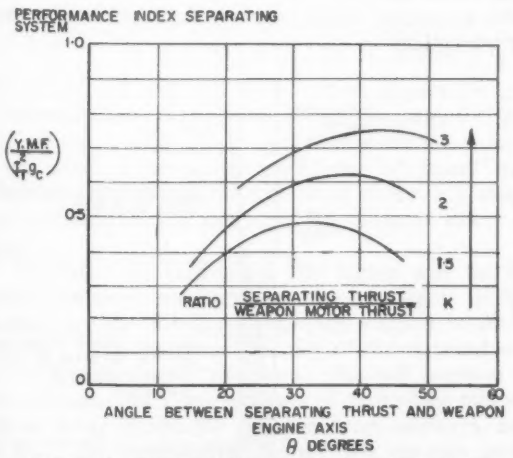


FIGURE 10. Results of the theoretical analysis of the separation path.

*The derivation of this equation is given in the Appendix.

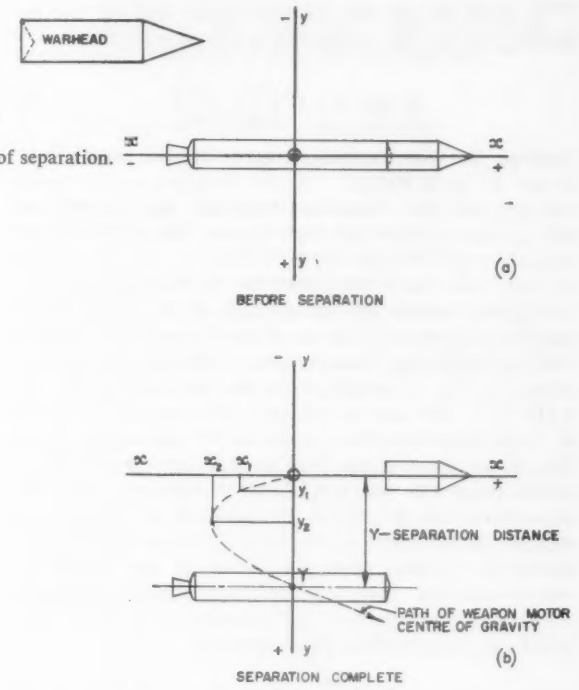


FIGURE 9 (*above*). Reference axes and separation path.

a maximum value of $YMF/I_T^2 g_c$. Fig. 10 shows graphs of $YMF/I_T^2 g_c$ against θ for several values of K and we see that the ratio of separating thrust to weapon motor thrust is going to be the limiting factor for performance.

During the separation the motor case will be subjected to a bending moment which will depend on the thrust and position of the separating motors. The neatest way to arrange the separating motors is to bury them in two equal groups at the front and rear of the weapon motor, for then there are no excrescences to give rise to extra aerodynamic drag and, also, the ends of the motor are more rigid and better suited to taking thrusts than the middle. With this arrangement the weapon motor may be treated as a simply supported beam carrying a uniformly distributed inertial load (*see* Fig. 11). A maximum bending moment occurs at the centre and the stress it induces will depend on the rapidity of loading. By assuming that the bending moment is suddenly applied we can study how the shape of the weapon motor determines the maximum thrust and the direction of the separating motors.

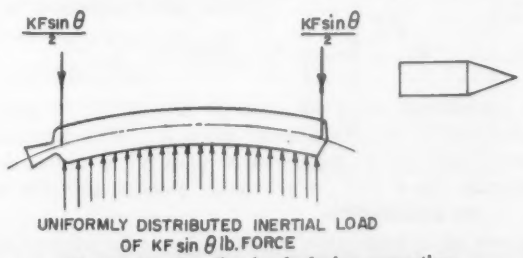


FIGURE 11. Bending loads during separation.

It is found that the weapon motor will not fail by bending during the separation if (*see* Appendix)

$$K \sin\theta \not> 0{\cdot}67 \left(\frac{D}{d}\right)^2 \left(\frac{D}{L}\right) \quad . \quad . \quad (5)$$

where D the internal diameter of the motor case in feet

L the distance between the groups of separating motors, *i.e.* the length of the weapon motor in feet

d the throat diameter of the nozzle in feet.

Typical values for (D/d) and (L/D) would be 4 and 10 respectively and so $K \sin\theta$ should not exceed 1·07. Combining this condition with Fig. 10 we can construct Fig. 12 which shows the maximum values of $YMF/I_T^2 g_c$ that can be obtained with various values of K if the weapon motor is not to be damaged. From Fig. 12 we see that the best separating motor thrust is about twice the weapon motor thrust and that the separating motors should be inclined at 33° to the weapon motor axis. If the (L/D) ratio of the weapon motor is reduced, then the thrust of the separating motors and the values of $YMF/I_T^2 g_c$ can be increased.

From Fig. 12 the best performance of the separating system is described by the expression

$$\frac{YMF}{I_T^2 g_c} = 0{\cdot}61 \quad . \quad . \quad . \quad (6)$$

If $\frac{M_0}{g_c}$ = the weight of the weapon motor at launch, in slugs

JM_0 = the thrust of the weapon motor in lb. force,

$\frac{\beta M_0}{g_c} = \frac{M}{g_c}$ slugs,

then $$\frac{YM_0^2 \beta J}{I_T^2 g_c} = 0{\cdot}61$$

and $$I_T = M_0 \sqrt{\left(\frac{Y\beta J}{0{\cdot}61\, g_c}\right)} \quad . \quad . \quad (7)$$

This is the total impulse of the separating motors needed to give a separation distance of Y feet. If the overall specific impulse of the separating motors and mountings is taken to be 100 lb. sec./lb., then the weight of the separating system is $0{\cdot}0022 M_0 \sqrt{(Y\beta J)}$ lb. weight; expressed as a percentage of the weapon motor weight at launch this is $0{\cdot}22\sqrt{(Y\beta J)}$ per cent. The separating motors will take a short time to neutralise the thrust of the weapon motor and disengage it from the warhead. During this time some lateral impulse will be given to the warhead and this impulse should be predictable once the rate of thrust build-up of the separating motors is known.

Consider Fig. 13. Here it has been assumed that the separating motors reach their full thrust in 0·030 secs., that the thrust increases linearly with time up to the full value, and further, that the separation begins immediately the weapon motor thrust has been neutralised, *i.e.* when the thrust of the separating motors has reached $F/\cos\theta$ lb. force. Thus the weapon motor will begin to separate from the warhead after a time of $0{\cdot}030\,(F/\cos\theta)\,(1/KF)$ secs. During this time the average lateral thrust of the separating motors is $F \sin\theta/2\cos\theta$ lb. force and so the lateral impulse will be $(0{\cdot}030/K\cos\theta)(F\sin\theta/2\cos\theta)$ lb. secs. Assuming that K is equal to 2 and θ is equal to 33° the lateral impulse becomes $0{\cdot}0072\,F$ secs. Now F is equal to JM_0 and the minimum weight of the missile will be $\lambda M_0/g_c$ slugs, at all burnt, where λ is the structural factor for the missile. Therefore the maximum lateral velocity of the warhead caused by the separation will be $0{\cdot}0072\,(JM_0 g_c)/(\lambda M_0)$ ft./sec., *i.e.* $0{\cdot}24\,(J/\lambda)$ ft./sec. If the weapon motor is separated before all burnt then the lateral velocity of the warhead will be less than this.

Now the weight of the separating motors will depend on the range variation that is needed for a particular missile and the way in which the range is to be varied. For example, if the range of a missile is to be changed solely by altering the thrusting time of the weapon motor then the separating system must be designed to cope with the circumstances of the shortest range when the weapon motor is at its heaviest. If, on the other hand, little variation in missile range is needed, or a large variation is needed, and it is permissible to alter the range by altering the trajectory of the rocket and then slightly changing the terminal velocity of the warhead, then the separating motors will only have to deal with a weapon motor which is light and nearly empty of propellant.

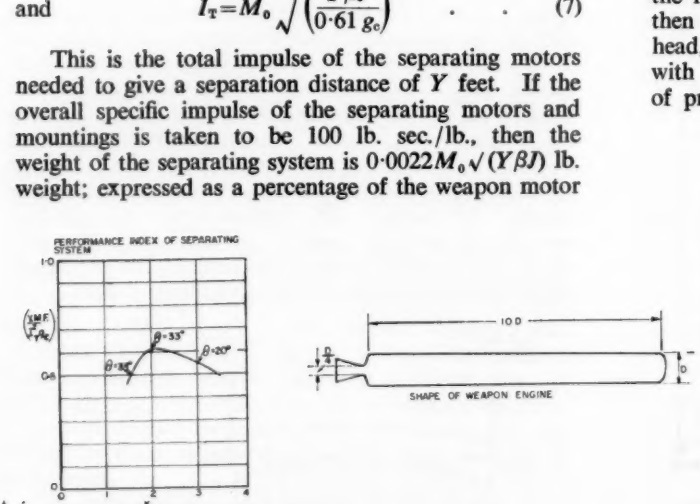


FIGURE 12. Graph showing the best performance that can be obtained with a separating system without damaging the weapon motor sketched above.

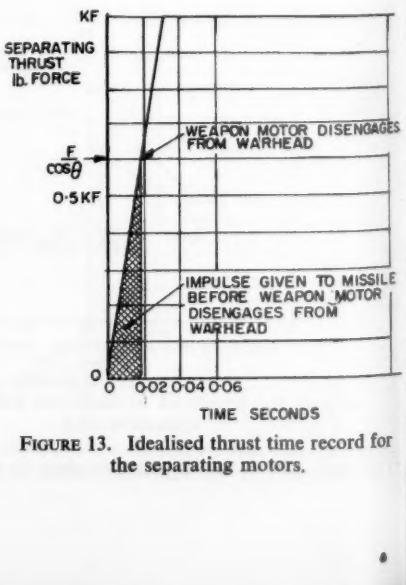


FIGURE 13. Idealised thrust time record for the separating motors.

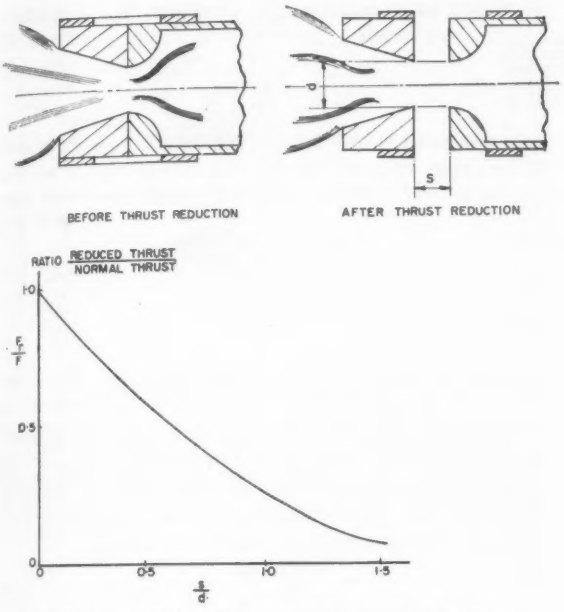


FIGURE 14. Variable thrust nozzle of Fraser and Rowe.

Another important factor is the separation distance, Y. This should be large enough to ensure that the warhead will not be damaged or pushed off course by the rocket jet as the weapon motor overtakes the warhead. The value of Y will depend on the thrust of the weapon motor and the altitude at which the separation is done. Each missile should be treated individually to decide upon a suitable separation distance but, to get some idea of separating motor weights now, it will be assumed that a separation distance of 20 ft. is adequate.

Consider now a hypothetical missile where the thrust to weight ratio of the weapon motor, J, is 2·5 and where the structural factor, λ, is 0·2. If the weapon motor must be separated early in its burning time, we assume that $\beta\left(\text{ratio } \frac{\text{weapon motor weight at separation}}{\text{weapon motor weight at launch}}\right)$ does not exceed 0·6 and find that a 20 ft. separation can be effected with a separating system weighing 1·2 per cent of the weight of the weapon motor at launch. If separation is not needed until near "all burnt" and β is then, say, 0·2 then the separating system will weigh 0·75 per cent of the weight of the weapon motor at launch.

The later the separation, the higher will be the lateral velocity acquired by the warhead during separation. For example, when the weapon motor is only half burnt the lateral velocity of the warhead will be one ft./sec.; near "all burnt" this will increase to three ft./sec. By using two sets of separating motors, one set firing backwards and one firing sideways, and by firing the backward-facing set first we can avoid pushing the warhead sideways. However, this arrangement is more complicated than the one studied in this paper and it would be about 50 per cent heavier.

The time for the separation can be estimated from the arguments in the Appendix. The separation is rapid, being complete in just over one second.

3. Control of Thrust Magnitude

Certain missiles may require a stage of reduced thrust before complete cut-off. The proposal of Fraser and Rowe for a variable thrust nozzle is fully reported elsewhere[3]; this nozzle operates by separating the expansion cone from the throat and its characteristics are illustrated in Fig. 14. There are two other methods of thrust reduction and these are based on the fact that when attempting an interruption, if the chamber throat area is not enlarged enough then the motor continues to burn at a much reduced pressure.

3.1. REDUCTION BY SEVERING THE MOTOR NOZZLE

The normal thrust can be reduced by blowing off the motor nozzle and increasing the throat area to a value which is insufficient to extinguish the charge. By manipulating the well known equations that are used to determine the equilibrium burning pressures in solid propellant rockets we may show that: —

$$\frac{F_r}{F} = \frac{C_{F_r}}{C_F}\left(\frac{A_r}{A_t}\right)^{-\left(\frac{n}{1-n}\right)} \quad . \quad . \quad (8)$$

where F and F_r are respectively the thrust of the motor before and after nozzle severance, C_F and C_{F_r} are respectively the thrust coefficients of the motor nozzle before and after severance, A_t and A_r are the chamber throat areas before and after nozzle severance and n is the exponent in the propellant burning rate law*. If the remaining portion of the nozzle acts as a choke then $C_{F_r}=1{\cdot}25$. For a nozzle of high expansion ratio we may take $C_F=1{\cdot}7$ at high altitude and so

$$\frac{F_r}{F} = 0{\cdot}74\,V_r^{-\left(\frac{n}{1-n}\right)} \quad . \quad . \quad (9)$$

where A_r/A_t has been replaced by V_r which will be called the venting area ratio. With the venting hole acting as a choke the peak thrust will lie between $F(1{\cdot}48V_r-1)$ and $F(0{\cdot}74V_r)$.

3.2. REDUCTION BY RADIAL VENTING

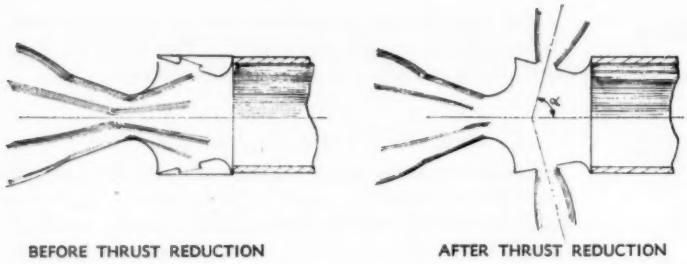
If the area of the holes of a radial venting device is chosen carefully, then on venting the engine will continue to burn at a much reduced thrust.

By studying the axial thrust components produced by the main nozzle and the radial holes of the radial venting device we may deduce an equation of the same type as equation (9), namely

$$\frac{F_r}{F} = V_r^{-\left(\frac{1}{1-n}\right)}\left\{1 - \frac{C_F'}{C_F}(V_r-1)\cos\alpha\right\} \quad . \quad (10)$$

where F_r, F, V_r and C_F have the same significance as in equation (9), C_F' is the thrust coefficient of the radial holes and α is the angle of inclination of the radial holes. By selecting suitable values for V_r and α any required

*The burning rate of a propellant is proportional to the pressure over the burning surface raised to the power n.



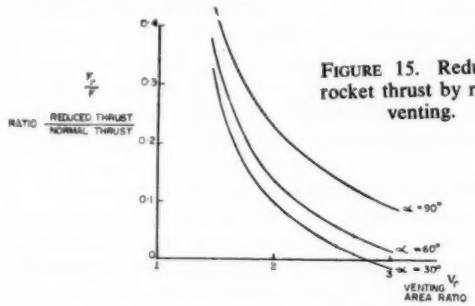


FIGURE 15. Reducing rocket thrust by radial venting.

thrust reduction may be obtained. The venting area ratio V_r must be small enough to avoid an interruption of burning. As the radial holes or nozzles have a smaller expansion ratio than the main nozzle (for the sake of compactness) their thrust coefficient, C_F' will be smaller. Then taking $C_F'=1{\cdot}4$, $C_F=1{\cdot}7$ and $n=0{\cdot}54$ as before,

$$\frac{F_r}{F}=V_r^{-2{\cdot}18}\{1-0{\cdot}82\,(V_r-1)\cos\alpha\} \quad . \quad (11)$$

This relationship is shown for three values of α in Fig. 15 and it can be seen that reversals of thrust, as well as drastic reductions, are possible with the radial venting device.

3.3. UTILISATION OF PROPELLANT AT REDUCED THRUST

The specific impulse of a propellant in a given rocket motor can be defined as

$$\frac{\text{Thrust}}{\text{Rate of discharge of propellant}}$$

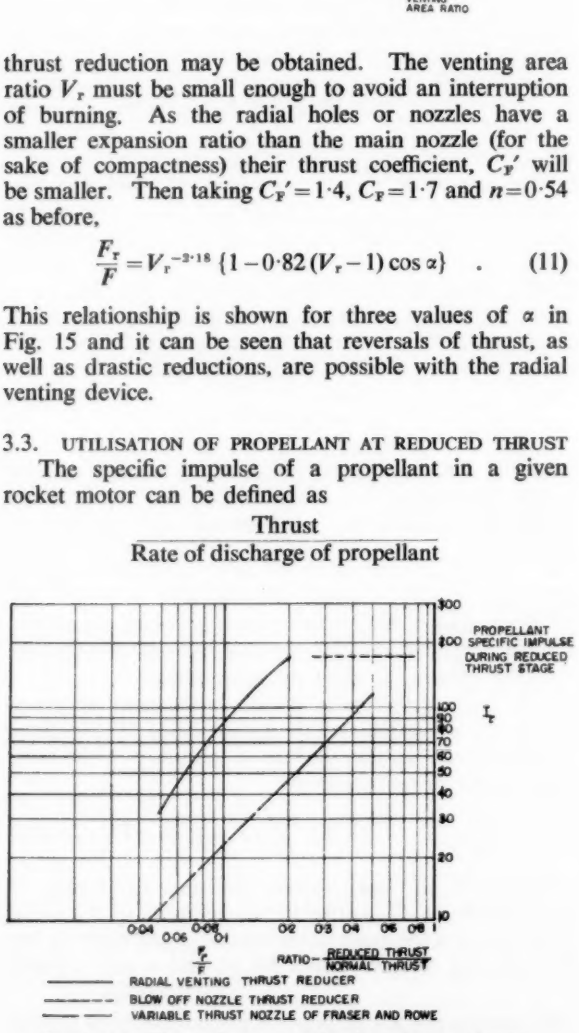

PROPELLANT SPECIFIC IMPULSE DURING REDUCED THRUST STAGE
RATIO REDUCED THRUST / NORMAL THRUST
RADIAL VENTING THRUST REDUCER
BLOW OFF NOZZLE THRUST REDUCER
VARIABLE THRUST NOZZLE OF FRASER AND ROWE

FIGURE 16. The performance of various thrust reducers.

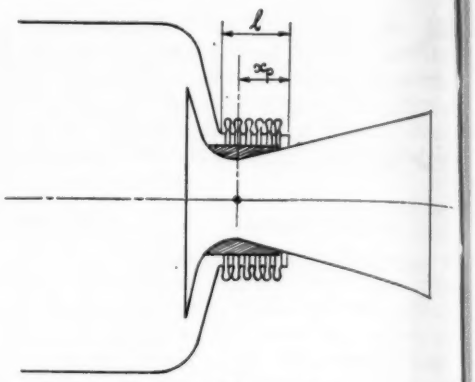


FIGURE 17. Swivelling nozzle.

In the variable thrust nozzle of Fraser and Rowe[3] the throat size is fixed so the rate of discharge of the propellant does not change when the thrust is reduced. Therefore the specific impulse of the propellant falls when the thrust is reduced and we may write,

$$\frac{I_r}{I}=\frac{F_r}{F} \quad . \quad . \quad . \quad (12)$$

where F_r and F have their previous meanings and I_r and I are respectively the specific impulses of the propellant after and before thrust reduction.

For the severed nozzle the specific impulse before severance is

$$I=\frac{C_F A_t P}{N_D A_t P}=\frac{C_F}{N_D}$$

where C_F is the thrust coefficient and N_D is the discharge coefficient* of the nozzle. After severance the thrust coefficient falls to C_{F_r} and if we assume that N_D remains unaltered, then

$$\frac{I_r}{I}=\frac{C_F}{C_{Fr}} \quad . \quad . \quad . \quad (13)$$

If the nozzle acts as a choke after severance then a typical value for $I_r/I=0{\cdot}74$. If we assume, as we do throughout this section, that the atmospheric pressure is so low that a reduction of motor pressure has an unimportant effect on pressure ratio and that combustion is also unaffected, we may conclude that I_r is independent of the amount of thrust reduction.

For the radial venting device the thrust relationship before and after venting is given by equation (11). The specific impulse of the propellant before venting is

$$I=\frac{F}{N_D A_t P}$$

where A_t is the throat area of the main nozzle and P is the burning pressure. After the venting operation it is

$$I_r=\frac{F_r}{N_D\,(A_t+a_r)\,P_r}$$

*N_D is not a true discharge coefficient in the hydraulic sense but is a constant defined by the equation: Rate of discharge of propellant gases $=N_D\times$ nozzle throat area $\times$ propellant burning pressure.

where a_r is the total area of the radial holes and P_r is the burning pressure after venting. Therefore

$$\frac{I_r}{I} = \frac{P}{P_r}\left(\frac{A_t}{A_t + a_r}\right)\frac{F_r}{F} \quad . \quad . \quad (14)$$

Now P/P_r depends on the exponent in the burning rate law for the propellant and the venting area ratio and it may be shown that $P/P_r = V_r^{2\cdot18}$ when the exponent is 0·54 and so

$$\frac{I_r}{I} = V_r^{2\cdot18} \cdot \frac{1}{V_r} \cdot \frac{F_r}{F}$$

$$= V_r^{1\cdot18} \cdot \frac{F_r}{F} \quad . \quad . \quad . \quad (15)$$

and the radial venting device is $V_r^{1\cdot18}$ times as efficient as the variable thrust nozzle of Fraser and Rowe. For the best use of the propellant then the venting area ratio V_r should be as big as possible without risking an interruption. Assuming the maximum permissible value of V_r to be 3, the highest efficiency of the radial venting device becomes

$$\frac{I_r}{I} = 3\cdot66\frac{F_r}{F} \quad . \quad . \quad . \quad (16)$$

Equation (11) can be used to determine the angle of inclination of the radial nozzles needed to obtain any desired thrust ratio.

Specific impulse is plotted against thrust ratio for all three devices in Fig. 16. A specific impulse of 235 lb. sec./lb. has been assumed for the propellant before thrust reduction. The Fraser-Rowe nozzle is seen to be the least efficient of the three devices, but all the devices become very inefficient at low thrust ratios. Trimmer motors with an overall specific impulse of about 130 lb. sec./lb. would be lighter than thrust reducers for $F_r/F < 0\cdot15$. However, with thrust reducers there is no problem of thrust asymmetry as with externally mounted pairs of trimmer motors, and the missile motor nozzle and its control system can be used for steering the missile during the reduced thrust stage.

4. Control of Thrust Direction

Jet deflection systems which are applicable to solid propellant rockets have been discussed elsewhere[1, 2, 4], and so they will not be considered here. Swivelling nozzles have been described[1, 2], and they have the attraction of being light and causing no loss to total thrust when the thrust line deviates from the axis of the vehicle. A moving gas tight seal can be obtained by using flexible metal bellows to connect the nozzle to the motor. Although these bellows would be very thin they could be preserved from the heat of the propellant gases by placing them in a stagnant gas space around the nozzle throat, as depicted in Fig. 17. Unless the bellows fit snugly around the throat of the nozzle the gimbal ring will have to bear a rearward load of some magnitude

$$P(A_B - C_F A_t) \quad . \quad . \quad (17)$$

where A_B is the effective cross-sectional area of the bellows. For a motor with a long burning time, which uses an uncooled nozzle, it is likely that the effective bellows area will be sufficiently bigger than the nozzle throat area to cause a load on the gimbal ring between half and full motor thrust. A small gimbal load and control force are possible with a thin-walled, water-cooled nozzle and such a device will be discussed later.

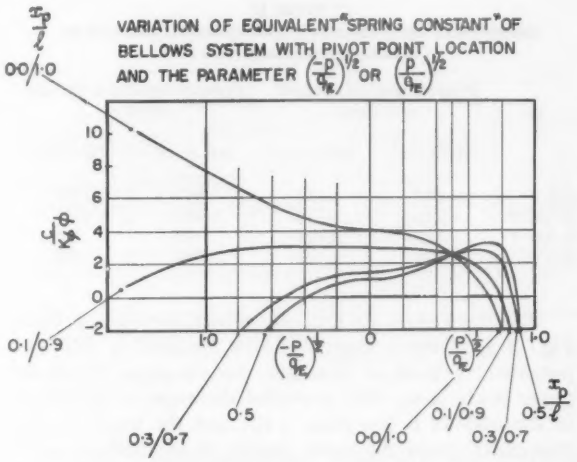


FIGURE 18. Reproduction of Figure 3 of Reference 8.

Seide[8] has given some data on pressurised bellows actuator systems which enables us to make an estimate of the forces likely to be needed to control the movement of a swivelling nozzle. He describes both theoretical calculations and some experimental work with two multiply bellows: one of 3 in. and the other of 13 in. diameter. The larger of these two bellows is of greater interest and it will be used as a basis for the following discussion of swivelling nozzle design.

Important bellows characteristics taken from Tables 2(*a*) and 2(*b*) of Seide's paper are given in Table I and a reproduction of Fig. 3 (page 433, from the same paper) is shown here in Fig. 18.

NOTATION

- C the moment applied to pressurised bellows (in. lb.)
- k_ϕ the ratio of applied moment to the rotation of one end of the unpressurised bellows with respect to the other
- l length of bellows (in.)
- q_E buckling pressure of clamped bellows (lb./in.²)
- x_P distance of pivot point from movable end of bellows (in.)
- ϕ rotation of bellows (radians).

TABLE I
IMPORTANT BELLOWS CHARACTERISTICS

Item	*Value*
Outside diameter (in.)	13·67
Inside diameter (in.)	12·42
Length (in.)	3·23
Number of plies	12
Ply thickness (in.)	0·005
Number of convolutions	8
k_ϕ lb. in./degree	163
q_E lb./in.²	870

TABLE II

THEORETICAL FRICTIONLESS CONTROL MOMENTS FOR A 13 IN. DIAMETER PRESSURISED BELLOWS

$\frac{xp}{e}$	*Pressure applied to inside of bellows*		*Pressure applied to outside of bellows*	
	300 lb./in.²	500 lb./in.²	300 lb./in.²	500 lb./in.²
0/1·0	+280	−115	+905	+1030
0·1/0·9	+345	+115	+492	+476
0·3/0·7	+445	+426	−82	−280
0·5	+476	+510	−246	−575

Referring now to Fig. 18, which is derived from Fig. 3 of Seide's paper; in the original a different parameter is used as abscissae, but on page 434 of his paper Seide states that, provided the angle of deflection of the bellows is less than $\pm 12°$ and the length is less than three times the mean radius of the bellows cross section, then the parameters which he uses may be replaced by

$$\left(\frac{P}{q_E}\right)^{\frac{1}{4}} \text{ and } \left(\frac{-P}{q_E}\right)^{\frac{1}{4}}$$

This has been done in Fig. 18.

Also, the moment applied to the bellows, C, can be taken to increase linearly with the angle of deflection θ. P is taken to be positive when the pressure is applied to the inside of the bellows. Finally, the ratio x_P/l describes the location of the pivot point for the actuator system which is sketched in Fig. 17.

Assuming motor burning pressures of 300 and 500 lb./in.² and gimbal pivot point location ratios of 0/1·0, 0·1/0·9, 0·3/0·7 and 0·5, values for C/ϕ have been calculated for bellows subjected to both external and internal pressures and these values are given in Table II. Some of the values are negative, indicating that for certain gimbal pivot point locations the bellows will become unstable and deflect spontaneously. This fact enables us, by carefully selecting the position of the pivot point and the motor pressure (or bellows buckling pressure), to arrange for a negligible control moment.

Seide[8] also reported some experiments in which he subjected 4½ in. diameter bellows to external pressures up to 400 lb./in.² and the 13 in. diameter bellows to internal pressures up to 600 lb./in.². With both bellows

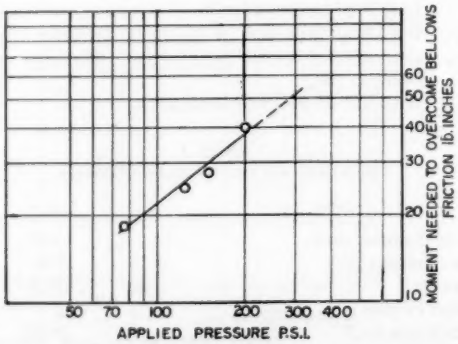


FIGURE 19. Hysteresis effect with small diameter bellows subjected to external pressure, estimated from Figure 6 of Reference 8.

he found the applied moment versus angle of deflection graph to exhibit hysteresis, but whereas with the smaller bellows (those under external pressure) the slopes, C/ϕ at various pressures agreed with the theoretical values, with the bigger ones, the slopes at each pressure were bigger than theory predicted. Seide attributed all deviations from the theoretical values to friction between the plies and not to friction in the gimbal pivot which he thought would be negligible. Seide gave five applied moment versus degree of deflection cycles for the 4½ in. diameter bellows, in Fig. 6 of his paper, and from these the moment needed to overcome friction has been estimated and plotted here in Fig. 19. Seide gave no indication of the magnitude of the hysteresis effect for the bigger bellows, but from results plotted in his Fig. 7(*b*) it seems that at an internal pressure of 300 lb./in.² the applied moment must be increased at the rate of 115 lb. in./degree of deflection to overcome the interply friction alone. A guess at the hysteresis effect with the 13 in. diameter bellows can be made by assuming that Fig. 19 is applicable, extrapolating it up to 300 lb./in.² and multiplying the answer by the factor:

$$\frac{\text{mean dia. of bigger bellows} \times \text{surface area of bigger bellows}}{\text{mean dia. of smaller bellows} \times \text{surface area of smaller bellows}}$$

whence we have a constant friction moment of 400 lb. in. To finish the sums we shall pivot the 13 in. diameter bellows at one end and wrap it around an uncooled nozzle of 8 in. throat diameter having a thrust coefficient of 1·7. Such a swivelling nozzle would develop a thrust of 25,000 lb. with a chamber pressure of 300 lb./in.², cause a gimbal ring load of 14,000 lb. and have, as far as can be estimated at present, the control moment characteristic shown in Fig. 20.

These calculations are uncertain and so we can only draw the following tentative conclusion: if swivelling nozzles for solid propellant motors are constructed from

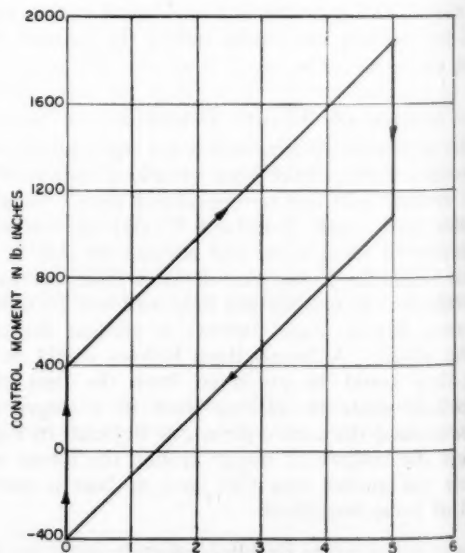


FIGURE 20. Estimated control moment characteristic of 8 in. throat diameter swivelling nozzle.

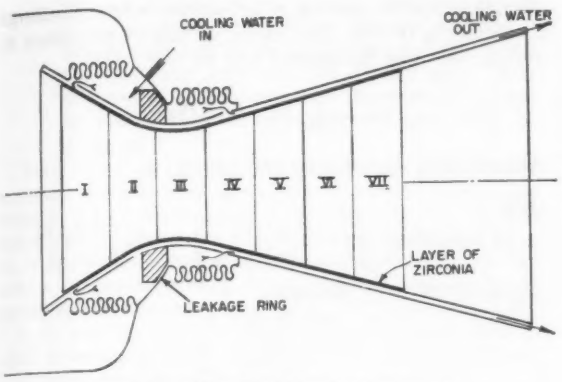


FIGURE 21. Water cooled swivelling nozzle.

uncooled nozzles and multiply bellows, then the control system will have to overcome friction which will be comparable to that encountered with gimbal-mounted liquid propellant motors, because the load on the gimbal bearings is likely to be of a similar magnitude and, in addition, there will be interply friction. If it were thought desirable to reduce the bellows friction several things could be done: a bellows could be made from fewer, but thicker plies, and although it would then have a greater elastic stiffness this could always be offset by a judicious choice of the pivot position; alternatively interply lubrication might be possible with solid or liquid lubricants. Finally, the most elaborate way of minimising nozzle control forces would be to use thin single ply bellows supported by a fluid under pressure as shown in Fig. 21. Here the front single ply bellows are supported by cooling water at the engine chamber static pressure. The cooling water leaves the front bellows by flowing through the cooling channels around the nozzle and leaking through a narrow gap between two spherical faces. Leakage water can rejoin the water flowing through the cooling channels downstream of the nozzle throat. By carefully choosing the cooling water injection pressure and the dimensions of the leakage ring and nozzle throat (*see* Fig. 21) the load on the spherical bearing can be made very small. With this design a 10 in. throat diameter nozzle could be accommodated within a 13 in. diameter bellows. Three advantages accrue from the use of water cooling: the nozzle wall can be thin and light, the gimbal load and friction can be very small and there will be no interply friction in the bellows. However, cooling water must be carried in the vehicle under pressure and the quantity will now be estimated.

All heat transfer data for the gas side of the nozzle are taken from Bartz[9] and for the coolant side from McAdams[10]. Only that region of the nozzle near to the throat will be considered for cooling because we are primarily interested in reducing the wall thickness there; elsewhere the conventional heat sink construction for the nozzle wall will suffice. The part of the nozzle which is to be cooled has been given a protective layer of sprayed zirconia and is shown in Fig. 21 to be divided into seven regions of equal axial length for the purpose of calculation. Each region has been allotted one gas side heat transfer coefficient which has been estimated from the curve marked "case 1" in Fig. 4 and from equations (36) and (37) of Bartz's paper. Important physical quantities for the heat transfer calculations are given in Table III.

TABLE III
ASSUMED VALUES OF PHYSICAL QUANTITIES USED IN THE CALCULATIONS

Parameter	*Value*
Chamber pressure	300 lb./in.^{2}
Stagnation temperature	2,500°C
Conductivity of metal of nozzle wall	$4{\cdot}65\times10^{-4}$ C.H.U./in. sec. °C
Conductivity of sprayed zirconia layer	$1{\cdot}54\times10^{-5}$ C.H.U./in. sec. °C
Thickness of metal wall of nozzle	0·1 inch
Nozzle throat diameter	10 inches

The thickness of the layer of sprayed zirconia is to be uniform throughout the cooled part of the nozzle and is to be chosen to give that layer a maximum inside surface temperature of 1,950°C. At the throat the heat flux will be 1·11 C.H.U./(in.^{2}) (sec.) and from Fig. 22, which is a reproduction of McAdams'[10] Figs. 14-22, we can see that the cooling water will be able to absorb heat at such a rate if the outside wall temperature, T_w, exceeds the water saturation temperature, T_{sat}, by about 30/35°C. With the cooling water at a pressure of 300 lb./in.^{2}, T_{sat} is 214°C and so T_w will be, say, 245°C. Proceeding inwards a temperature rise of 236°C will occur across the stainless steel wall of the nozzle and a rise of 1,450°C across the sprayed zirconia layer, which therefore needs to be around 0·020 in. thick. Table IV summarises the calculations.

If cooling water is supplied to the nozzle at 15°C and is heated to 210°C then the rate of flow must be

$$\frac{1{,}183}{(210-15)} \approx 6 \text{ lb./sec.}$$

This flow of cooling water may be regarded as the ejection of a propellant of negligible specific impulse which will cause a reduction in the performance of the

TABLE IV
RESULTS OF THE HEAT TRANSFER CALCULATIONS

Station	*Area sq./in.*	*Gas side heat transfer coefficient C.H.U./(in.^{2}) (sec.) (°C)*	*Overall Heat transfer coefficient C.H.U./(in.^{2}) (sec.) (°C)*	*Heat transferred*	
				Through each region C.H.U./sec.	*Cumulative C.H.U./sec.*
I	225	$0{\cdot}95\times10^{-3}$	$0{\cdot}382\times10^{-3}$	200	200
II	160	1·57 „ „	0·463 „ „	170	270
III	136	2·0 „ „	0·495 „ „	153	523
IV	156	1·4 „ „	0·448 „ „	160	683
V	194	0·95 „ „	0·382 „ „	170	853
VI	225	0·63 „ „	0·321 „ „	165	1018
VII	260	0·49 „ „	0·281 „ „	165	1183

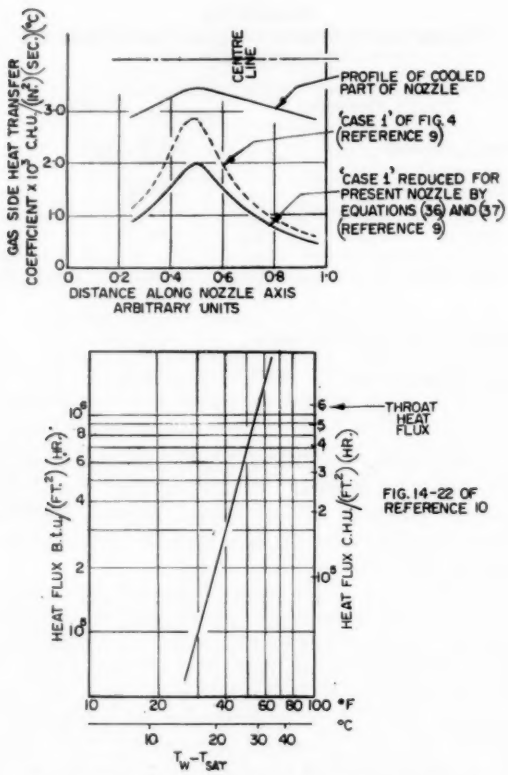

GAS SIDE HEAT TRANSFER COEFFICIENT x 10³ C.H.U./(ft²)(SEC.)(°C)
CENTRE LINE
PROFILE OF COOLED PART OF NOZZLE
'CASE 1' OF FIG. 4 (REFERENCE 9)
'CASE 1' REDUCED FOR PRESENT NOZZLE BY EQUATIONS (36) AND (37) (REFERENCE 9)
DISTANCE ALONG NOZZLE AXIS ARBITRARY UNITS
HEAT FLUX B.t.u./(ft²)(hr.)
HEAT FLUX C.H.U./(ft²)(hr.)
THROAT HEAT FLUX
FIG. 14-22 OF REFERENCE 10
°F
°C
$T_W - T_{SAT}$

FIGURE 22. Heat transfer data for water cooled nozzle calculations.

motor. A fixed weight attached to the motor when no cooling water is present would cause a similar reduction in performance and we shall now try to estimate what fixed weight penalty is equivalent to a cooling water flow rate of 6 lb./sec.

Consider two rockets: each has a propellant weight of m_p and a structural weight of m_s (this includes the weight of any pipes, valves and tanks for the cooling water). One rocket carries a weight m_w of cooling water and the other a fixed weight m_e so that both will reach the same "all burnt" velocity in gravitationless, drag-free flight. The water-carrying rocket will eject (m_p+m_w) of propellants having an average specific impulse of

$$\frac{I \cdot m_p}{m_p+m_w} \text{ lb. sec.}$$

and will reach a velocity of

$$\frac{I \cdot m_p}{m_p+m_w} \cdot g \cdot l_n \cdot \frac{m_p+m_w+m_s}{m_s} \text{ ft./sec.}$$

The rocket carrying the fixed weight will eject m_p of propellant at a specific impulse I and have the same final velocity but given by a different expression, namely

$$I \cdot g \cdot l_n \cdot \frac{m_p+m_s+m_e}{m_s+m_e} \text{ ft./sec.}$$

By equating these two expressions and assuming values for m_s and m_w we can calculate m_e. For a 10 in. diameter nozzle ejecting a propellant whose discharge coefficient is 0·0068, the discharge rate of propellant at 300 lb./in.² will be around 160 lb./sec., and

$$m_w = \frac{6}{160} m_p = 0{\cdot}0375\, m_p$$

Assume that $m_s = 0{\cdot}2 m_p$ and $m_e = k \cdot m_p$

then

$$(1-0{\cdot}0375)\, l_n \left(\frac{1+0{\cdot}2+0{\cdot}0375}{0{\cdot}2}\right) = l_n \frac{(1+0{\cdot}2+k)}{(0{\cdot}2+k)}$$

and so $k = 0{\cdot}0105$; therefore

$$\begin{aligned} m_e &= 0{\cdot}0105\, m_p \\ &= 0{\cdot}28 \quad m_w \\ &= 0{\cdot}053 \quad m_s \end{aligned}$$

With a coolant flow rate of 6 lb./sec. the equivalent fixed weight finally becomes $1{\cdot}68\, t_B$ lb., where t_B is the motor burning time in secs. Unless the saving in fixed weight in the nozzle itself and in its actuators, by the use of cooling water, is greater than m_e the use of a water-cooled swivelling nozzle is obviously not justified. Less cooling water would be needed if either the cooled area were reduced or the thickness of the zirconia layer were increased.

5. Conclusions

There are many devices and methods which may be used to control the propulsive effect of a solid propellant rocket. An attempt has been made here to discuss several of these methods and devices in some detail. Big thrust variations and almost instantaneous thrust cut-offs are possible and with development the swivelling nozzle may become the lightest and easiest device yet available for steering a rocket vehicle. Any increase in versatility of the solid propellant motor must be paid for by a greater increase in complexity and inert weight but, with ingenuity, these costs need not be high.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Maxwell and Mr. Jessen of R.P.E., Westcott for their helpful comments and suggestions.

APPENDIX

THEORETICAL STUDY OF FORCIBLE SEPARATION

(*i*) In this analysis it is assumed that the mass of the weapon engine stays constant throughout the separation. This is nearly true for the separation is over in about one second and the weapon engine will have lost only a small fraction of its propellant in this time.

(*ii*) The atmosphere surrounding the rocket is so tenuous that it has no effect on the movement of the weapon engine during the separation.

The reference axes used in the analysis have the following characteristics:—

(*a*) Before separation (Fig. 9*a*) the origin coincides with the centre of gravity of the weapon engine and the *xx* axis coincides with the axis of the missile.

(*b*) During the separation (Fig. 9*b*) the direction of the reference axes in space is fixed and so is the

distance of their origin from the centre of gravity of the warhead. It is found that the warhead is moved sideways by the separation but any effects this movement may have are ignored here. With this system of reference axes the effect of gravity on the motions of the various bodies may be neglected.

From 0 to x_1 y_1 (*see* Fig. 9*b*) the burning weapon motor is pushed sideways and backwards by a steady separating thrust of KF lb. force acting at an angle θ to the weapon engine axis. During this period the centre of gravity of the weapon motor moves along a straight path. At the point x_1 y_1 the separating thrust stops and the centre of gravity of the weapon motor traces out a parabola from x_1 y_1 to pass through the point 0, Y. The separation is taken to be complete at the point 0, Y and the distance Y is called the separation distance.

We shall now calculate the relationship between the quantities Y, I_T, K and θ which are defined as follows.

The mathematical analysis of the separation path

NOTATION

- F Forward thrust of the weapon motor in lb. force
- KF Total thrust of the separating motors in lb. force
- I_T Total impulse of the separating motor in lb. sec.
- M Mass of the weapon motor and the separating
- g_c motors during the separation (assumed constant) in slugs
- Y The separation distance in feet (*see* Fig. 9*b*).

Motion in the x direction

0 to x_1

The separating thrust component acting on the weapon motor is $-F(K\cos\theta-1)$ lb. force and so the acceleration is $\frac{-Fg_c}{M}(K\cos\theta-1)$ ft./sec.^{2}. After a time of $\frac{I_T}{KF}$ secs. the weapon motor reaches x_1 with a velocity of $\frac{I_T g_c}{M}\frac{(K\cos\theta-1)}{K}$ ft./sec. The distance traversed during this period is $x_1=\frac{I_T^2 . g_c}{2MF}\frac{(K\cos\theta-1)}{K^2}$ feet.

x_1 to x_2

The separating thrust has stopped and so the weapon motor acceleration suddenly changes to $+(Fg_c)/(M)$. At x_2 the weapon motor velocity is zero and so the distance between x_1 and x_2 is $-\frac{I_T^2 g_c}{2MF}\frac{(K\cos\theta-1)^2}{K^2}$ feet. Between x_1 and x_2 the weapon motor spends $\frac{I_T}{F}\frac{(K\cos\theta-1)}{K}$ secs., making the time from 0 to x_2, $(I_T/F)\cos\theta$ secs.

x_2 back to 0

A distance of $-\left\{\frac{I_T^2 g_c}{2MF}\frac{(K\cos\theta-1)^2}{K^2}+\frac{I_T^2 g_c}{2MF}\frac{(K\cos\theta-1)}{K}\right\}$ ft. must be retraced by the weapon motor to complete the separation. This distance will be traversed at an acceleration of $+\frac{Fg_c}{M}$ ft./sec.^{2} and so the point 0 will be reached in $\frac{I_T}{F}\sqrt{\left[\frac{(K\cos\theta-1)+(K\cos\theta-1)^2}{K^2}\right]}$ secs. giving a total time for the separation of

$$\frac{I}{F}\left\{\cos\theta+\sqrt{\left[\frac{(K\cos\theta-1)+(K\cos\theta-1)^2}{K^2}\right]}\right\}\text{ secs.}$$

Motion in the y direction

0 to y_1

The acceleration in this direction is $\frac{KFg_c\sin\theta}{M}$ ft./sec.^{2} for $\frac{I_T}{K_F}$ secs. and so the weapon motor moves $\frac{I_T^2 g_c\sin\theta}{2KFM}$ ft. to y_1 where it has a velocity of $\frac{I_T g_c\sin\theta}{M}$ ft./sec.

y_1-Y

From y_1 onwards the weapon motor coasts with a velocity of $\frac{I_T g_c\sin\theta}{M}$ ft./sec. for a time of

$$\frac{I_T}{F}\left\{\cos\theta+\sqrt{\left[\frac{(K\cos\theta-1)+(K\cos\theta-1)^2}{K^2}\right]}-\frac{1}{K}\right\}\text{ secs.}$$

covering a distance of

$$\frac{I_T^2 g_c}{MF}\sin\theta\left\{\cos\theta+\sqrt{\left[\frac{(K\cos\theta-1)+(K\cos\theta-1)^2}{K^2}\right]}-\frac{1}{K}\right\}\text{ ft.}$$

The total separation distance, Y, therefore becomes

$$\frac{I_T^2 g_c\sin\theta}{MF}\left\{\cos\theta+\sqrt{\left[\frac{(K\cos\theta-1)+(K\cos\theta-1)^2}{K^2}\right]}-\frac{1}{2K}\right\}\text{ ft.}$$

and rearranging the expression for Y we have:—

$$\frac{Y . M . F}{I_T^2 g_c}=\sin\theta\left\{\cos\theta+\sqrt{\left[\frac{(K\cos\theta-1)+(K\cos\theta-1)^2}{K^2}\right]}-\right\}\frac{1}{2K}$$

The thrust of the separating motors

NOTATION (*see* Fig. 5)

- d the throat diameter of the weapon motor in feet
- D the internal diameter of the weapon motor tube in feet
- L the length of the weapon motor body in feet
- P the weapon motor burning pressure in lb. force/ft.^{2}
- t the wall thickness of the weapon motor case in feet
- σ the maximum permissible tensile stress in the tube wall in lb. force/ft.^{2}.

The thrust developed by the weapon motor is given by the expression: nozzle thrust coefficient × nozzle throat area × motor pressure, and so

$$F=\frac{1\cdot5 . \pi . d^2 . P}{4}\text{ lb. force.}$$

(Taking 1·5 as the thrust coefficient for the separating motor nozzles.) Therefore the side thrust of the separating motors is $KF\sin\theta$, *i.e.* $\frac{1\cdot5 . \pi . d^2 . P . K . \sin\theta}{4}$

The maximum bending moment in a simply supported beam carrying a uniformly distributed load is equal to:—

$$\frac{\text{The total load on the beam} \times \text{the beam span}}{8}$$

For the motor sketched in Fig. 11 this is

$$\frac{1\cdot5 . \pi . d^2 . P . K . \sin\theta . L}{32}\text{ lb. force feet}$$

The maximum stress produced in an elastic beam by a suddenly applied bending moment is equal to:—

$$2 \times \frac{\text{the bending moment}}{\text{the modulus of the beam cross section}}$$

For a thin-walled tube of circular cross section the modulus is $\frac{\pi . D^2 . t}{4}$ cu. ft. Now the thickness of the tube wall has been designed so that the hoop stress caused by the internal motor pressure shall be σ lb. force/ft.^{2} and so t is equal to $(PD)/(2\sigma)$ ft. The modulus of the tube cross section is then $\frac{\pi PD^3}{8\sigma}$ cu. ft. and the maximum bending stress in the tube wall is

$$\frac{2 . 1{\cdot}5 . d^2 . P . K . \sin\theta . L . 8 . \sigma}{\pi . P . D^3 . 32} \text{ lb. force/ft.}^2.$$

Simplifying we have a stress of

$$0{\cdot}75\, K \left(\frac{d}{D}\right)^2 \left(\frac{L}{D}\right) \sigma \text{ lb. force/ft.}^2.$$

This stress will be tensile on one side of the motor and compressive on the other. There is already a longitudinal tensile stress of $\sigma/2$ lb force/ft.^{2} in the tube wall caused by the internal pressure and so the maximum tensile stress produced by the bending moment must not exceed $\sigma/2$ lb force/ft.^{2}. Therefore

$$0{\cdot}75\, K \left(\frac{d}{D}\right)^2 \left(\frac{L}{D}\right) \sigma \not> \frac{\sigma}{2}$$

and

$$K \sin\theta \not> 0{\cdot}67 \left(\frac{D}{d}\right)^2 \left(\frac{D}{L}\right)$$

This, then, is the design criterion for a separating system.

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TECHNICAL NOTES

The Application of the Schlieren-Interferometer to the Study of Supersonic Flow Around Unyawed Axi-Symmetric Bodies*

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1. INTRODUCTION

This note describes our recent attempts to apply the schlieren-interferometer to the study of supersonic flow around axi-symmetric bodies at zero incidence, and in particular shows how the density field distribution for a cone has been derived.

Various optical techniques, *e.g.* shadowgraph, schlieren and interferometric, have been used in the study of gas flows where density changes are significant. In some instances, however, a qualitative investigation is insufficient and although it is possible to obtain quantitative data from most optical methods, the interferometer has proved, so far, to be the most valuable in this respect. Up to the present time three different interferometers have been used for aerodynamic work:—

(*a*) The Mach-Zehnder interferometer[1],
(*b*) The diffraction grating interferometer[2],
(*c*) The schlieren-interferometer[3].

Of these, the Mach-Zehnder interferometer has been used extensively in both two-dimensional and axi-symmetric flow studies, while the other two have only recently been introduced. The relative merits of each of these interferometers are not considered here, although the Mach-Zehnder is used as a basis for comparison.

The schlieren-interferometer† is so called since it essentially combines the schlieren and interferometric principles, *i.e.*, density gradients in the flow field are deduced from finite or infinite fringe patterns produced by the interference of two wave fronts from a coherent source. It was first used at O.N.E.R.A. France[3] to study two-dimensional phenomena. Studies of the flow over two-dimensional wedges, with sharp leading edges[4] have also been made by the authors: this work describes in detail the interpretation and reduction of the interferograms for two-dimensional flow. No comparable studies have yet appeared, using the schlieren-interferometer for the analysis of flows around axi-symmetric bodies.

NOTATION

Δx	fringe shift
K	Gladstone-Dale constant
λ	wave length of light
b	fringe spacing
δ^*	non-dimensional fringe shift. $\delta^*=\Delta x/b$
δ	optical path length difference. $\delta=\lambda\delta^*$
s	model image duplication distance
M	free stream Mach number
ρ_0	free stream density
η	index of refraction
θ_c	cone semi angle
θ	interface angle of Wollaston prism
ε	angular separation of rays after splitting at the first Wollaston prism
Z	axial distance

SUBSCRIPTS

β	denotes ordinary ray
α	denotes extraordinary ray
0	free stream conditions.

2. DESCRIPTION OF INTERFEROMETER

The principle of most interferometers is understood to be the interference of two wave fronts produced from a coherent source. To produce interference it is necessary that the two wave fronts suffer a path length difference relative to each other. This may be either purely geometric or due to a change in refractive index, since path length is defined as the product of the refractive index of the medium and the length or width of the medium, through which the waves travel.

Figure 1 shows a general arrangement of the interferometer. Consider the central ray emanating from the source; it passes through the polariser P_1 which has a two-fold purpose. First, it ensures that the ray is polarised at 45° to the optic axis of the Wollaston prism, thus giving equal intensities to both extraordinary and ordinary rays produced therein. Second, the Fresnal-Arago laws are satisfied.

The ordinary and extraordinary rays produced at the Wollaston prism W_1 are plane polarised in mutually perpendicular directions and the angular separation of the two rays is given by:—

$$\tan\varepsilon=2(\eta_\alpha-\eta_\beta)\tan\theta$$

For quartz crystals this equation becomes

$$\tan\varepsilon=0{\cdot}018\tan\theta$$

The rays emergent from W_1 are made parallel by the lens M_1 and traverse the working section with a lateral displacement denoted by s the dedoublement or image duplication distance. The lens M_2 then brings the rays to focus at the focal point of M_2, on or near to which is the second prism W_2. Here the splitting action of the first prism is partly or totally compensated. For instance, in the production of infinite fringes the splitting action is totally compensated (Fig. 1*c*), whereas with finite fringes the splitting action is only partially compensated (Fig. 1*b*).

Now before either fringe pattern can be produced, the two wave fronts emerging from the second prism W_2 have to be brought into the same plane of polarisation for interference. This is accomplished by the analyser P_2. However, in the finite fringe case, because it is necessary to move W_2 from the focus of M_2, it has been found that there is only one position of W_2 relative to the screen which will give focused fringes.

*Based on a Junior Lecture given to the Coventry Branch of the Society in December 1960.
†Translated from "La strioscopic interferentielle."
Originally received April 1961.

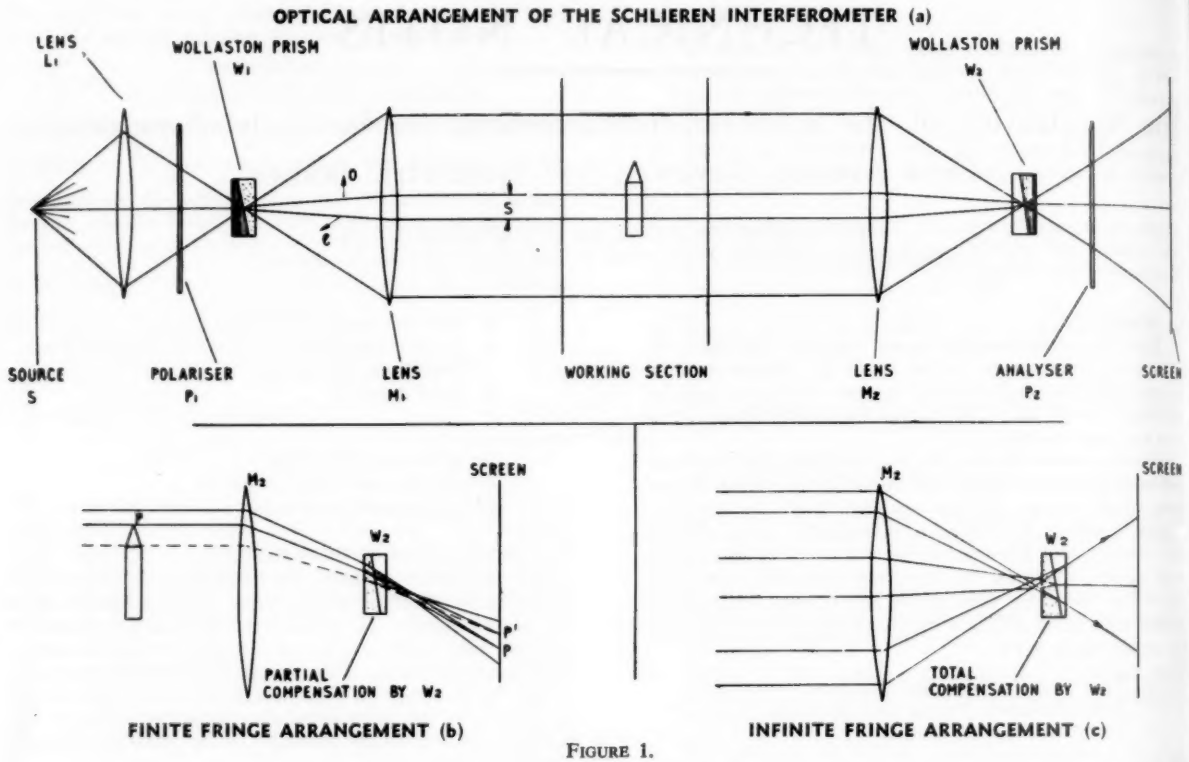

FIGURE 1.

3. INTERPRETATION OF INTERFEROGRAMS

When the interferometer is correctly adjusted, two images of the model can be seen (Fig. 2), the separation of which represents the separation of the ordinary and extraordinary rays in the working section. The reason why two images of the model are seen is that through each point in the field there passes an ordinary and an extraordinary ray, but as each of these rays is refracted differently at the second Wollaston prism (Figs. 1*a* and 1*b*) two images appear. However, it is only the upstream image of the model that is of interest.

In the Mach-Zehnder interferometer, which uses a large beam separation, one of the rays can be made to pass through an undisturbed region which is taken as a reference point in calculating the density change. Therefore the fringe shift at each point in the field gives directly a continuous variation of total path length difference. The schlieren-interferometer has by comparison a small beam separation such that both rays pass through the disturbed flow field (except for a limited region) and hence there is no fixed reference point. Thus we have only changes in path length difference from point to point in the field. However, if we can find the total path length difference variation from some datum point or region, then we are able to deduce the density variation throughout by using the Mach-Zehnder reduction procedure.

It is a simple matter to obtain the total path length difference, since it will be recalled that the fringe shift is proportional to the change in path length difference of two rays a distance s apart, so all that is necessary is to sum the differences at all points s apart along a line parallel to the model image duplication, between a point and the reference field, *e.g.* upstream image of a shock. Depending also on the beam separation, there is clearly visible a small region extending a distance s from the boundary of the undisturbed field into the disturbed field, *e.g.* between the two shock images, where the fringe pattern is identical to that produced with a Mach-Zehnder interferometer.

4. METHOD OF REDUCTION

In axi-symmetric flow the density distribution is found by evaluating numerically the following integral equation:—

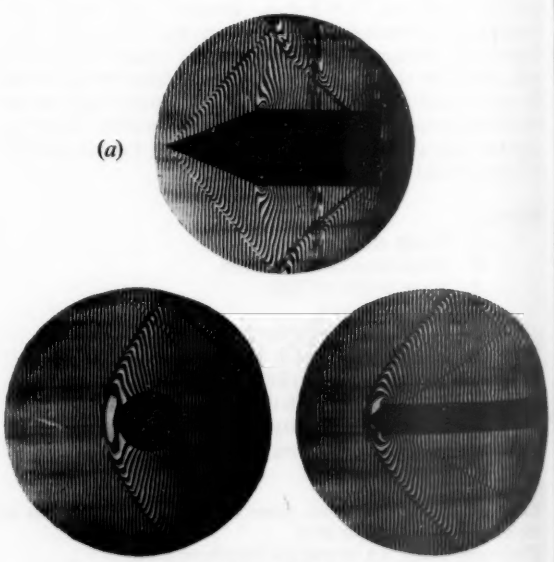

FIGURE 2. Examples of schlieren interferograms.

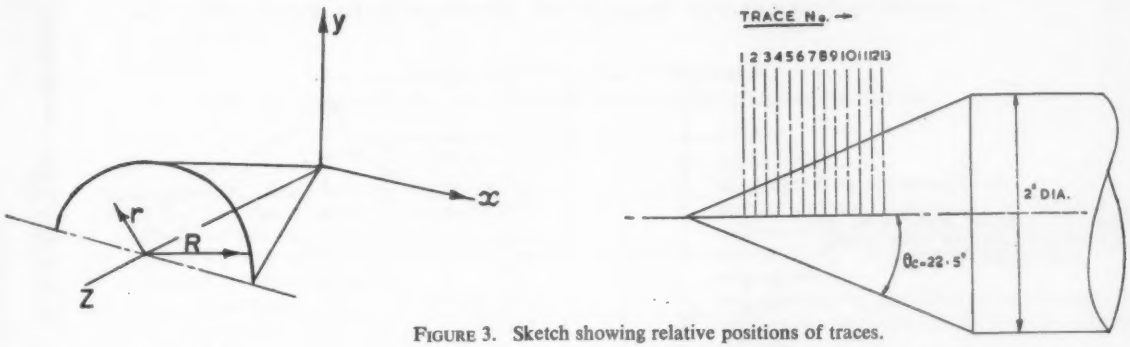

FIGURE 3. Sketch showing relative positions of traces.

$$\rho(r)-\rho_0=-\frac{1}{\pi K}\int_r^R \frac{d\delta(y)}{dy^2}\,dy^2/\sqrt{(y^2-r^2)} \quad . \quad (1)$$

It can be shown easily that the relationship between change in path length difference $\Delta\delta$ and fringe shift Δx is given by:—

$$\Delta\delta=\frac{\lambda\Delta x}{b} \quad . \quad . \quad . \quad . \quad (2)$$

For the purposes of measuring fringe shifts, a suitably enlarged photograph consistent with good fringe definition is required. The larger the photograph from which measurements are made the smaller the error in $\frac{\Delta x}{b}$.

A plot of Δx along a line of evaluation is then made. The next step is to sum the values of Δx occurring at intervals of s from the point of zero fringe shift, *i.e.* the shock position (note that the second image of the shock occurs at a distance s from the first, and also that it corresponds to the point of maximum fringe shift). The curve obtained by the summation procedure is a plot of the total fringe shift equivalent to that measured from a Mach-Zehnder interferogram of the same phenomena.

To solve the integral equation (1), it is necessary to know the total path length difference variation along lines perpendicular to the axis of symmetry. Thus, if other than a horizontal fringe interferogram is used, a series of cross plots will be required to obtain $\delta(y)$.

5. DESCRIPTION OF TESTS

The supersonic flow field around a cone was chosen for a quantitative analysis using the schlieren-interferometer, because of the available theoretical data on its density field distribution. The tests were carried out on a cone of 22·5° semi-angle, base diameter 2 in. in the Armstrong Whitworth 10 in. × 8 in. intermittent tunnel at a Mach number of 1·55. A Z configuration was adopted for setting up the schlieren-interferometer so that the two lens shown in Fig. 1, *i.e.* M_1 and M_2 were replaced by spherical mirrors. The light source consisted of a 130 watt projector lamp, located at the focus of M_1. This arrangement was convenient, but it meant that we were restricted

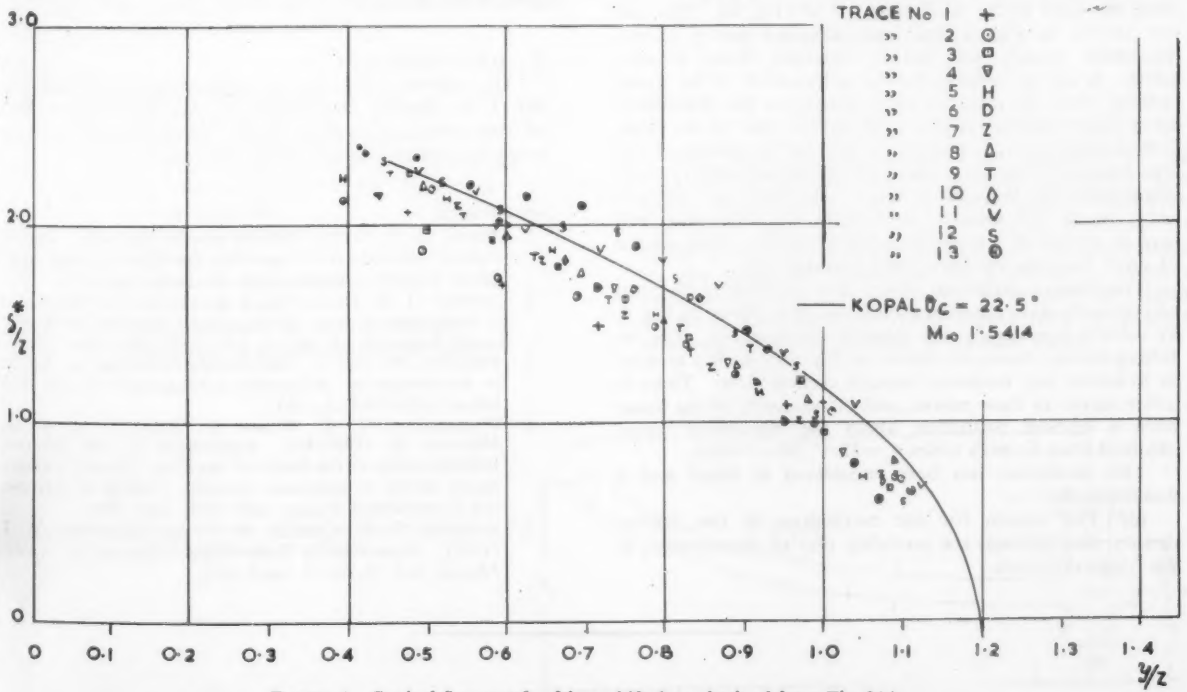

FIGURE 4. Conical flow test for fringe shift data obtained from Fig. 2(*a*).

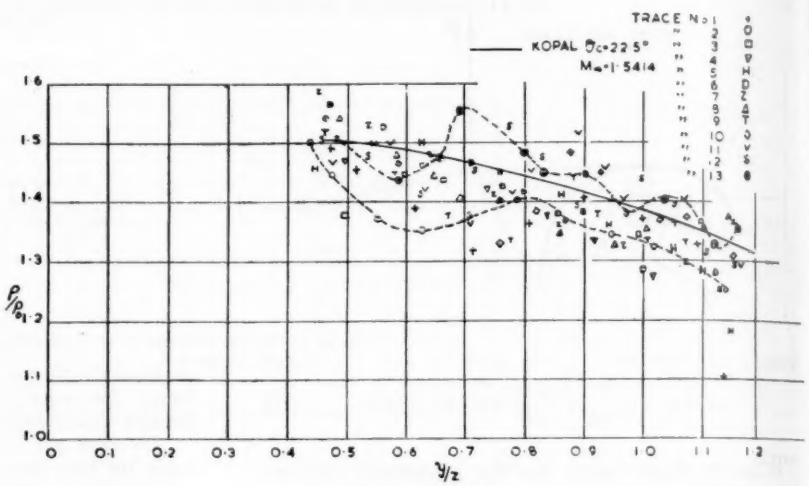

FIGURE 5. Conical Flow Test of (p/p_0) values obtained from fringe shifts plotted in Fig. 4.

to finite fringe interferograms. A monochromatic source was obtained by using a narrow-cut filter centred at 4,561Å for which a matching blue sensitive film was used. Other interferograms were taken to illustrate fringe patterns associated with other axi-symmetric bodies (Fig. 2).

6. RESULTS AND DISCUSSION

The results for the cone shown in Fig. 2(*a*) are now discussed. Following the measurement of fringe shifts and summation along lines of evaluation, cross plots were made to obtain the variation of total path length difference along lines perpendicular to the axis of symmetry, *i.e.* $\delta(y)$. The relative spacing of these lines is shown in Fig. 3. Before evaluating the density field, the fringe shift data have been used to test for conical flow, by plotting the reduced fringe shift $\delta^*/Z=(\Delta x/b)/Z$ (where Z denotes the axial length from the apex to the line) against y/Z (Fig. 4). The full line shown in Fig. 4 has been obtained for a known theoretical density distribution obtained from Kopal's tables. It will be noticed that the values of δ^*/Z for traces farthest from the apex lie more closely to the theoretical curve than those for traces close to the apex of the cone. One possible source of error is due to the extent of the free stream at the apex, where the disturbed field is small compared with the free stream. Therefore any disturbances in the free stream, particularly near the apex, will lead to errors in the summed fringe shifts. This source of error has not yet been fully investigated.

The density variations along lines normal to the axis of symmetry were computed from the data shown in Fig. 4, by solving numerically the integral equation (1). The resulting density traces are shown in Fig. 5 in such a manner as to reveal any tendency towards conical flow. There is a fair scatter in these results, and the majority of the traces have a marked oscillation about the theoretical curve, obtained from Kopal's tables $\theta_0=22{\cdot}5°$, $M=1{\cdot}5414$.

This oscillation has been considered in detail and it was found that:—

(*a*) The reason for the oscillations in the derived density distributions are probably due to inaccuracies in the fringe shift data.

(*b*) The numerical reduction procedure (*see* Ref. 3) used is well behaved.

7. CONCLUSION

The results obtained for the density field around the cone, although not in good agreement with theory, do indicate that the method provides results comparable with those expected from a Mach-Zehnder Interferometer. To obtain reasonably accurate density distributions it is essential to have accurate fringe shift data rather than to increase the number of steps over the interval of integration. Furthermore, it should be noted that the case of the cone gives effectively the worst possible error, since the density changes in the field are small. The density fields obtained for blunt bodies should be correspondingly more accurate.

8. ACKNOWLEDGMENT

The authors would like to express their appreciation to Mr. J. R. Busing, Department of Aerodynamics, College of Aeronautics, Cranfield for his general advice and the loan of schlieren-interferometer equipment.

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Vibration of Centrally Stiffened Rectangular Plate

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1. INTRODUCTION

Natural frequencies of free flexural vibration of rectangular plates may, in many cases, be considerably increased by attaching to the plate one or more elastic stiffening ribs parallel to one edge, or by casting or machining the plate and stiffeners integrally.

Hoppmann[1] has determined by a semi-empirical method the natural frequencies of an integrally stiffened simply-supported square plate, using the concept of a homogeneous orthotropic plate of uniform thickness having elastic compliances which are equivalent to those of the stiffened plate. Filippov[2] has obtained the exact solution for the fundamental frequency of a simply-supported square plate having a number of equally spaced stiffeners and has considered the effect of point loads applied to the stiffeners in a direction perpendicular to the plane of the plate. In a recent paper[3] the present author has obtained by exact and approximate methods natural frequencies of stiffened rectangular plates having a variety of boundary conditions and stiffener-configurations. Exact expressions for natural frequencies are obtained by solving the differential equation of motion of a rectangular plate, the resulting frequency equations usually being extremely tedious to solve. Approximate methods of analysis employ the Rayleigh[4] method, in which the maximum kinetic energy of the stiffeners and plate are equated to their maximum strain energy. To determine the strain and kinetic energies, it is necessary to choose a suitable vibration form for the plate which satisfies the boundary conditions approximately. However, since an assumed vibration form is equivalent to imposing constraints on the plate, the resulting frequency will be higher than that obtained by exact analysis.

NOTATION

A cross-sectional area of stiffener
A_1, A_2 amplitudes of vibration
a length of plate parallel to stiffener
b ½ (width of plate) perpendicular to stiffener
D flexural rigidity of plate, $Eh^3/12(1-\mu^2)$
E Young's modulus
e ½ (width of stiffener)
f depth of stiffener
g acceleration due to gravity
h thickness of plate
I second moment of area of stiffener about axis in middle surface of plate
$K = A_2/A_1 - 1$
P_1, P_2 functions of (a/b) defined in text
p_s, p_0 natural circular frequencies of stiffened plate and unstiffened plate respectively, radians/sec.
T_p, T_s kinetic energy of plate and stiffeners respectively
U_p, U_s strain energy of plate and stiffeners respectively
W maximum deflection of plate from unstressed position
x, y co-ordinate distances in plane of plate
μ Poisson's ratio
ρ weight per unit volume

2. FUNDAMENTAL FREQUENCY OF RECTANGULAR PLATE, SIMPLY-SUPPORTED ALONG TWO OPPOSITE EDGES, CENTRALLY STIFFENED PARALLEL TO THE REMAINING FREE EDGES

An exact frequency equation in this case would be extremely difficult to solve by virtue of the boundary conditions at the free edges of the plate, namely

$$\frac{\partial^2 W}{\partial y^2} + \mu \frac{\partial^2 W}{\partial x^2} = 0, \quad \frac{\partial^3 W}{\partial y^3} + (2-\mu) \frac{\partial^3 W}{\partial y \partial x^2} = 0;$$

therefore a simpler approximate solution is sought based upon the Rayleigh method. The flexural vibration form of half the plate in a direction perpendicular to the central stiffener will be similar to that shown in Fig. 1, and since the plate is simply-supported at the boundaries perpendicular to the stiffener, an approximate vibration form for the fundamental mode may be written

$$W = [A_1 + (1 - \cos \pi y/2b)(A_2 - A_1)] \sin \pi x/a \text{ or}$$

$$W = [1 + K(1 - \cos \pi y/2b)] \sin \pi x/a \qquad (1)$$

where

$$K = A_2/A_1 - 1 \text{ and } A_1 = 1.$$

The fundamental frequency of vibration is now obtained by equating the sum of the maximum strain energy of the stiffener and plate to the sum of their maximum kinetic energies. In equation (1) the vibration form of the plate in the y-direction could have been represented by the exact vibration form of a cantilever beam of uniform cross section. However, to simplify the algebra in the present analysis a simple cosine form is chosen to represent approximately the y-vibration form.

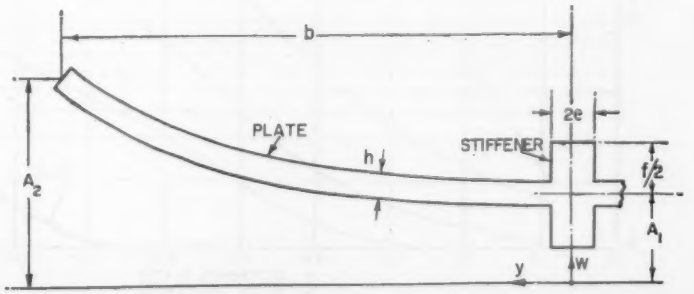

FIGURE 1. Vibration form of half of plate viewed parallel to length of stiffener.

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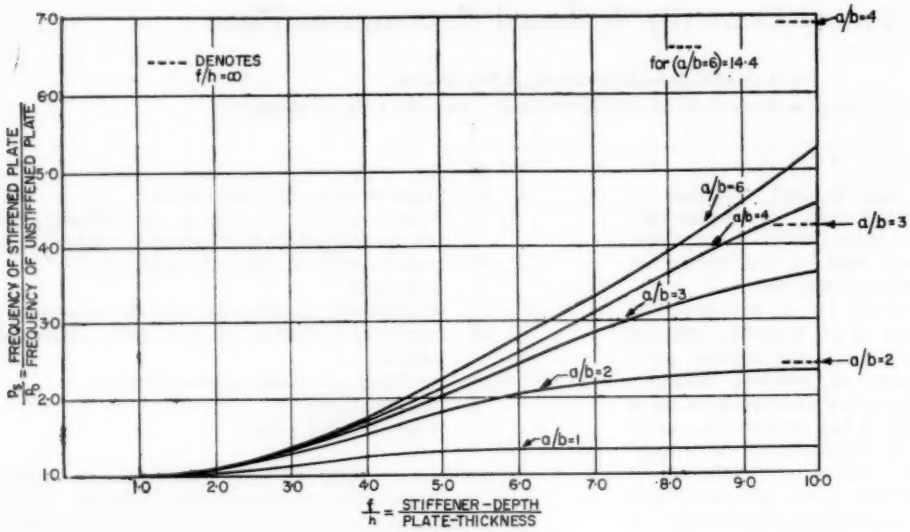

FIGURE 2.

The strain energy of the plate in an extreme position of flexural vibration is

$$U_p = \frac{D}{2}\int_0^a\int_0^b \left(\frac{\partial^2 W}{\partial x^2}\right)^2 + \left(\frac{\partial^2 W}{\partial y^2}\right)^2 + 2\mu\,\frac{\partial^2 W}{\partial x^2}\,\frac{\partial^2 W}{\partial y^2} + 2(1-\mu)\left(\frac{\partial^2 W}{\partial x \partial y}\right)^2 dxdy \quad . \quad . \quad . \quad . \quad (2)$$

and the kinetic energy of the plate at zero deflection is

$$T_p = \frac{\rho h}{2g} p_s^2 \int_0^a\int_0^b W^2 dxdy \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The strain energy of bending of the stiffener is

$$U_s = EI/2 \int_0^a \left(\frac{d^2 W}{dx^2}\right)^2 dx \quad . \quad . \quad . \quad (4)$$

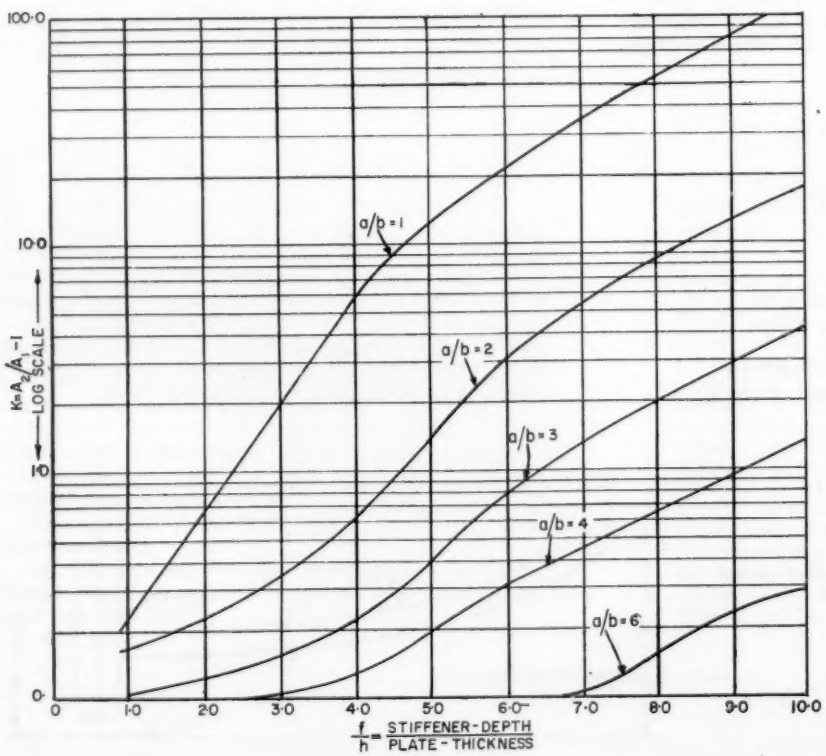

FIGURE 3.

and the kinetic energy of the stiffener is

$$T_s=\frac{\rho A}{2g}p_s^2\int_0^a W^2dx \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where, for the stiffener $W=A_1\sin\pi x/a$.

Substituting equation (1) into equations (2) through (5), the fundamental frequency equation is found by equating equations (2)+(4) to equations (3)+(5). Thus the natural circular frequency is given by

$$p_s^2=\frac{\pi^4gD}{2a^4\rho h}\left[\frac{P_1K^2+P_2K+2(1+EI)/bD}{0{\cdot}225K^2+0{\cdot}73K+(1+A/bh)}\right] \quad . \quad . \quad (6)$$

where

$$P_1=0{\cdot}45+0{\cdot}31\,(a/b)^2+(a/2b)^4$$

and

$$P_2=1{\cdot}46-0{\cdot}19\,(a/b)^2 \quad . \quad . \quad . \quad (7)$$

The frequency obtained from equation (6) will be higher than that obtained by an exact analysis, therefore to find the lowest value of the fundamental frequency the value of K must be found that will make p_s a minimum; *i.e.*

$$\frac{\partial p_s}{\partial K}=0.$$

If the right hand side of equation (6) is differentiated with respect to the parameter K and equated to zero, after a little simplification the following quadratic equation in K is obtained

$$K^2[0{\cdot}73P_1-0{\cdot}225P_2]+K[2\,(1+A/bh)P_1-0{\cdot}9(1+EI/bD)]+[P_2\,(1+A/bh)-1{\cdot}46\,(1+EI/bD)]=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

3. CALCULATION OF FUNDAMENTAL FREQUENCY

For given plate—stiffener parameters, equation (8) is solved in terms of K choosing the positive root, since for the fundamental mode A_2/A_1 will be positive. Frequencies are then calculated by substituting K in equation (6).

Variations of the ratio (frequency of stiffened plate/frequency of unstiffened plate) and "K," with the ratio (stiffener depth/plate thickness) are given in Figs. 2 and 3 respectively for a number of values of the ratio (a/b). For the purpose of calculating the curves in Figs. 2 and 3, the ratio of e/b was taken as 1/24 and μ as 0·3 for steel. Since the stiffener is situated on both faces of the plate it is assumed to bend about the plate middle-surface. In this manner it can be shown that $EI/bD=(e/b)\,(f/h)^2\,(1-\mu^2)$ and $A/bh=ef/bh$.

From equation (6) and equation (8) it can be shown that the ratio p_s/p_0 increases with the ratio (a/b) for a given value of (f/h), while the value of K decreases. When $(a/b)=$ infinity, K becomes zero and

$$p_s/p_0=\left[\frac{1+EI/bD}{1+A/bh}\right]^{\frac{1}{2}}.$$

When the value of (f/h) becomes great, the plate boundary-conditions along the stiffener approach that of a clamped edge and it can be shown that for a rigid stiffener the maximum frequency ratio is given by $p_s/p_0=1{\cdot}5\,(P_1)^{\frac{1}{2}}$ approximately. A more accurate fundamental frequency of a plate simply supported on two opposite edges, free on the third and clamped on the fourth, may be obtained by reference to a paper by Warburton[5].

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The Royal Aeronautical Society
The First Fifty Years

BY

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These abstracts from Captain Pritchard's "History of the Society" began in the March 1961 issue of the Journal.

1875-6

It has been recorded in the *Annual Reports* that Stringfellow made a trip to California with Frederick Marriott, who had been the publicity agent for Henson's project of 1843 and the subsequent experiments of Henson and Stringfellow. Marriott, who had become editor of the *San Francisco News Letter,* began to interest the Californians in a project of a large aeroplane partly lifted by gas, a project which had been suggested in previous years without number.

The 1875 *Annual Report* noted "The Californian flying machine again crops up—the sustaining power of gas, which was depended upon to help in part the action of the extended planes when propelled against the air, has been abandoned and the machine now consists wholly of plane surfaces, steam engine, and screw propellers. Instead of the planes being extended laterally, however, the three planes are superposed longitudinally, with an interval of about 10 feet. In length the whole structure is 120 feet, fixed upon a foundation of trussed bamboo. The planes are unequal in length, the largest on the top being of the above dimensions and about 40 feet wide. These three planes are rigidly supported by two masts about 40 feet high, and stayed by wire rigging."

It was proposed that the aeroplane should be launched down an inclined rail. The whole contraption had four propellers, two vertical and two horizontal, and had an estimated all-up weight of 1600 lb.

The Annual Meeting of the Society was held on 23rd June, in the Society of Arts, with James Glaisher in the Chair. Particular interest was attached to the meeting in view of the experiments of Moy and Shill with their Aerial Steamer, at the Crystal Palace. It had been announced that Moy would read a paper on what he and Shill had been doing.

Glaisher introduced the lecturer and his partner in optimistic terms.

"Two of our members, Messrs. Moy and Shill, have been spending, I should be sorry to say how much money,* more than that, they have been spending I do not know how much time; but I am not ignorant of the very high ability with which they have devoted themselves from time to time to the construction of a new steam engine on their own pattern. They have achieved a degree of success, which I could scarcely have expected last year, and they have now produced a machine which has lifted vertically a weight of 120 lb. This fact is so important and pregnant with our future success that I will not now longer occupy your time with speaking of it, as we have Mr. Moy here to explain to you what he has done and what he still expects this engine will be able to do."

Moy confessed that he had been studying the possibility of flight for thirty years, but for the first twelve of them he had believed the solution would come from the development of a dirigible.

"But in this period the steam engine has made some rapid strides, and engines of something less than one ton to the horsepower had been made, and I began to think that steam after all will be made available to propel aeroplanes, and that Henson and Stringfellow might have succeeded if they had more power, with a more effective imitation of nature."

The development of the Aerial Steamer, as described by Moy, was typical, in time at least, of modern practice.

"In 1869 I had settled the main feature of the aerial machine," he explained, and he was still carrying out modifications after over five years work. The experiments at the Crystal Palace had proved very disappointing to both Moy and his partner. They had been watched by members of Council, who believed they were working on the right lines. Unfortunately experiments on the lift and drag of plane surfaces had not provided that reasonable accuracy of data which might have led Moy to a result nearer to the answer he was trying to get. He was well aware, too, of the instability of his large model in free flight and had decided he could not afford the inevitable disaster which would occur, due to lack of control.

Moy had experimented in his workshop to test the possible lift he could obtain from the airscrews he had designed, and with his 3 h.p. engine he had lifted 120 lb., a result of some considerable significance in the light of the knowledge of the time, as Glaisher had noted.

Optimistically, however, after his many years of expensive research, Moy outlined his future activities.

"I propose to build an engine of 100 h.p., ascertain exactly what it will do by dynamometer, then build the aerial steamer with sufficient surface, cabin and accommodation, and steering apparatus to make it rise vertically from the ground . . . . to alter the angles of the aeroplane wheels and aeroplanes so as to travel in any required direction."

He proposed to build an all steel structure with the high wing-loading of 50 lb./sq. ft., and a consequent increase of speed. A cabin 70 ft. in length, 8 ft. deep was visualised.

"This will be of metal and a considerable portion of the roof and sides will be cellular, having about an inch of space between the outer and inner surfaces . . . . The space between the two surfaces is a receptacle for the exhaust steam." Water recovery in fact!

The object was not only to conserve the water supply for the steam engine but also to heat the cabins. Yes, cabins, for Moy also saw "no reason why cabins should not be made comfortable, and at whatsoever speed the steamer travels the aeronauts would never be exposed to the current of air."

Moy was not able to carry on with his schemes, for there was no one with sufficient knowledge to say whether the plans were completely wild cat or whether there was "something in them." It was not until forty years later that the first cabin aeroplane flew.

Although much time and attention had been given to papers and discussions on heavier-than-air problems, those of lighter-than-air were not neglected. James Glaisher was convinced that both methods could be pursued with advantage. As a research worker making use of the balloon, he had obtained a world reputation for the work he had done on behalf of the British Association. It was therefore natural that he should be able to give the Society an authoritative account of the disaster which had overtaken the great balloon which had risen from La Villette in April 1875. This balloon flight was undertaken, for scientific observations, by Messrs. Tissandier, Croce-Spinelli and Sivel. The balloon ascended to over 28,000 feet and cost the lives of the last two aeronauts.

All three were friends of Glaisher's, and he was able to speak with considerable authority and experience of

*In a letter to John Stringfellow, dated 22nd April 1875, Brearey gave some particulars of Moy's and Shill's experiments and added, "They have spent about £3,000 on this."

their work, especially in the knowledge of the very narrow escape he and Henry Coxwell had experienced in a similar high ascent. Glaisher himself commented that it was strange that all three men, "of different ages and different physique, should simultaneously have become exhausted. I have been at the height at which this occurred several times and never felt any inconvenience."

The one-time famous Captain Fred Burnaby took part in the discussion. His name had gone round the world after his ride to Khiva on horse-back and for his known willingness to undertake any adventure, whatever the risk attached to it. He took part in many balloon ascents and was elected a member of the Council of the Aeronautical Society in 1874. Burnaby, as a soldier, was anxious to find a method of determining the course of his balloon when out of sight of the ground, and he invented a method of dropping two parachutes, with a short interval between their releases. A silk cord connected them and the direction of the cord gave the direction in which the balloon was moving, which could be noted by compass. Burnaby made many night ascents, using magnesium flares carried by parachutes to determine the direction of movement.

Monsieur Menier, who read a paper in French, must have astonished quite a number of his hearers by his suggestion for steering hot air balloons. This suggestion was to make use of inclined planes or an inclined ring fixed round the balloon, to cause it to ascend at an angle. Thomas Moy promptly pointed out that the idea had been tried and failed at least fifty years previously, and Wenham drew attention to the work of Sir George Cayley on the subject.

The lecturer had demonstrated his case with two balloon models, one fitted with his apparatus and the other not. The former rose at an angle and the latter vertically, so, reported Brearey cautiously in the *Annual Report*, "The experiment was therefore, in a limited space and an undisturbed atmosphere, successful."

The *Annual Report* ended with three translations by Glaisher from the French. They were all very much concerned with flying at great height and the use of oxygen. The first two described the researches of M. Paul Bert, President of the Société Française Aérienne, on the effects of lack of oxygen, and of lowered barometric pressure. The third, a note by M. A. Gaudin to the French Society, gave particulars of oxygen breathing experiments as early as 1832.

The most curious part of the *Annual Report* was printed under the title, "Angus and Mack on the Air Path," with the note, "The following paper is inserted as being a popularised exponent of ideas upon the subject of aeronautics, and because the views put forth therein agree with the experiments and theories of several well-known members of the Aeronautical Society."

The paper was an argument between two Scottish engineers on the possibility of flight and the methods to obtain it, Angus for and Mack against. The argument is of considerable interest, as showing clearly the best ideas of the time about the fundamental problems of flying. It was written by Armour, a member of the Institute of Civil Engineers, who wrote "Wings for Man" and other papers for the JOURNAL.

Mack ends the discussion, which did not convince Angus, with the words, "An open highway to them in the air, and no one on it. Faith rules in other matters, and according to faith must it be here, where the eye sees not the road that has to be travelled, and where the action of belief is needed to develop the reality."

In October Brearey sent out a circular to the Members of the Society, "that a private trial of Mr. Simmons' Parakite will take place at the Alexandra Palace on Thursday 11th November . . . . A breeze of at least four miles an hour is necessary to success. The object of the experiment is to show the facility with which an observer can be elevated several hundred feet . . . so that should the retaining cord be fractured, he would descend as in a parachute."

Joseph Simmons was a balloonist, and in the previous year had taken out a patent for improvements in the construction of balloons. In July 1875 he took out a patent for parakites, a combination of parachute and kite, with, as the events proved, the virtues of neither, promising though the idea appeared to be.

The first demonstration at the Alexandra Palace in November failed. The wind was there to raise the parakites, but they proved uncontrollable. The experiments were witnessed by Brearey and a number of members, including Dr. Biddle, who had an idea for guiding balloons by means of sails! The idea was followed up by another member of the Society, in America, W. A. Eddy, but again without success.

During the following year Simmons was able to interest the War Office in the possibilities of his invention. In December 1876, only two days before Christmas, Simmons staged a demonstration at Chatham, in the presence of some of the chief officers of the School of Military Engineering.

"Mr. F. W. Brearey, honorary secretary of the Aeronautical Society of Great Britain," reported *The Times* on Christmas Eve, "was also on the ground. After some time had been occupied in preparing the larger of the two machines on the Lines, which machine had a surface of 700 sq. feet, an accident occurred which made the machine useless for the day. The wind was blowing very hard, and one of the arms which supports the covering of the machine was broken, and this broken spar having pierced the covering of the machine was no longer fit for use. A smaller machine was then tried, and it ascended to a good height; but the ballast attached not being enough, the machine was hauled down and another sandbag attached to it. But now the weight was too great; after ascending a little distance the parakite came down with a crash, sweeping along the ground, and knocking down a number of boys who were looking on . . . . Mr. Simmons had intended to go up with the parakite, had the preliminary trial been successful. Further experiments are to be made with it at Chatham."

Little more was heard of Simmons' invention. He joined the Balloon Society, which was founded some years later. It is convenient to give here further details of his exploits as a balloon pilot. I am indebted to Baden Powell's book on "Ballooning as a Sport."

In 1882 Colonel Burnaby, who had already done a good deal in the aeronautical line, and was on the Council of the Aeronautical Society, succeeded in crossing the Channel in a balloon. This created further interest in the subject. Sir Claude de Crespigny hired Mr. Simmons' balloon to attempt a similar feat, but an unfortunate accident at the start, in a violent wind, resulted in a broken leg and other injuries to Sir Claude, and Mr. Simmons was shot off in the air by himself. A remarkable Channel crossing was the result, for the aeronaut stated that it took only twelve minutes to go from coast to coast! This would imply a rate of fully two miles a minute, or 120 m.p.h. In 1883 quite a number of Channel crossings were made—Mr. Simmons going with Sir Claude de Crespigny from Maldon to Holland; Colonel Brine going over at last from Hythe; Simmons and Smale from Hastings; while two or three Frenchmen came across from France . . . ."

Years later, in May 1898, Dr. Biddle, writing to Baden Powell about the latter's paper on Kites in the current JOURNAL of the Society, said, "Old Brearey and I went to Alexander Palace to see poor Simmons try a model of his parakite—a tailless affair on the Chinese or Japanese armhole principle—it bounced about prodigiously owing probably to a slight want of adjustment. I came across Simmons, Wright and other aeronauts, including Burnaby of Khiva fame, in connection with the Balloon Society of which I was one of the earliest members—on my method

of steering balloons as exhibited at Woolwich to a committee of the W.O. . . . "

The end of 1875 saw the completion of ten years of the Society's existence. During the whole of those ten years Brearey had been at the aerial wheel, steering through the uncharted ocean of the air, but always confident that he was moving in the right direction. His name had become known wherever any experimenter was trying to solve the age-old problem, and he had carried on a constant correspondence with those inquirers who wished to know what people in England were doing.

At the General Meeting of the Société Française de Navigation Aérienne, held on 3rd December 1875, it was reported by Dr. de Villeneuve, Secretary-General of the Society.

" Our Society is not the only one which occupies itself in the study of Aerial Navigation. The Aeronautical Society of Great Britain has been founded these ten years by Mr. Fred W. Brearey, who performs the duty of Honorary Secretary, a position corresponding to that of Secretary-General with us."

After passing some complimentary observations upon Brearey's exertions in the cause, de Villeneuve added,

" The French Society thought it only justice to show its appreciation of his services by awarding him its Gold Medal. Mr. Willoughby, the English Vice-Consul, acknowledged the compliment paid to his countryman, and undertook to hand it over to Lord Lyons for transmission to the Duke of Argyll, the President of the English Society, who, at his Grace's residence, delivered the same to Mr. Brearey."

The Gold Medal was not awarded to Brearey without strong reason. In his ten years as Honorary Secretary Brearey, although he had little scientific or engineering knowledge, had thrown himself wholeheartedly into interesting all and sundry in Aerial Navigation. He not only corresponded with many who were experimenting, but drew from them their ideas and tried to improve upon them to the best of his ability. With practical experience he slowly began to learn certain fundamental ideas and to acquire a certain degree of skill in the construction of models.

In July 1869 John Stringfellow had made a suggestion to Brearey that he should give a lecture at Exeter. Although Brearey spoke deprecatingly of his own abilities, he was abounding in self-confidence, a self-confidence which grew faster than his competence, and amounted at times to an overwhelming conceit. In June 1879, for example, he wrote to Glaisher, " I am bold enough to say that there is not another man in the kingdom *more* competent than myself to form an opinion upon the merits of any invention for obtaining a fulcrum upon the air; simply because there is no man who has so persistently experimented. My whole time is devoted to the interests of the Society, and I find my whole time engaged."

Glaisher and Wenham, who came into close and constant contact with Brearey over the years, expressed quite different opinions of the capabilities of their energetic secretary in later years, opinions which would have shocked even Brearey out of his complacency. Brearey's supreme confidence enabled him to carry on where many a more technically competent man would have given up. At the end of the first ten years of the Society's life, he had learnt sufficiently to be prepared to give a series of lectures, illustrated with flying models, in a large number of towns in England and Scotland, and to bring to many thousands of people the possibilities of mechanical flight.

Those ten years had seen 16 general meetings of the members of the Society at which over 50 papers had been read and many more published in the *Annual Reports*. A world-wide interest had been created and the first Aeronautical Exhibition in the world had been held under its auspices. Under the Council's guidance the first wind tunnel in the world had been made and the first experiments, for purely aeronautical purposes, on plane surfaces to find the pressure in a current of air had been carried out. Men of science and engineering had lent their authority on the Council to the new Society and men of wide interests outside had also joined it.

The financial statement at the end of the ten years showed a balance of £32 in the Bank.

The next Annual Meeting of members was held on 9th June 1876, with Charles Brooke, F.R.S., member of Council, in the Chair. Mr. F. Cayley Worsley, a nephew of Sir George Cayley, at the meeting drew attention to the necessity of " very careful experiments in the very nicely adjusted science in which we are engaged. I do not hear that such experiments are being made at all on an effective scale," and added, " I have made many experiments for as long as the power lasted for the balancing, steering and adjusting to aerial apparatus . . . . I have seen many of the experiments of Sir George Cayley and I am convinced that we must have a convenient experimental power."

The problem of a suitable form of power arose at nearly every meeting of the Society.

" In my opinion," said Cayley's nephew, " there is a means of getting experimental power without going to the expense of steam engines or any large machinery, and the question was whether the Aeronautical Society was inclined to go into anything of that kind? I believe compressed air could be used as a temporary motive power. If they could get power to go 100 yards they could easily get power to go beyond that distance.

" I do not see," he confessed, " in what other way than by experiment we are to succeed with a machine which requires the marvellous adaptability of a bird. I would like to see a compressed air engine made which would give eight or ten minutes run: then the engineer would be able to take data. Without data it was an extremely difficult question which they had to contend with."

There is, nowadays, an outcry that there are too many data, and that an undigested mass of information is beginning to prove too much for the aeronautical stomach. There is, indeed, bound to be, in a world which insists upon moving at heavenly speeds, in formation which can only be digested by the angels in the solitudes of the outer space, where the points of no return are reached.

The aeronautical adventurers of the 1870's were exploring the beginnings of those uncharted roads which will never have any " Road up " signs, although they may have warning devices to say " Caution. Planes overhead, planes underneath."

The Council of the Society in 1876 " thought it judicious to include in the *Annual Reports*, as far as space would allow, all the literature upon the subject which is worth reproducing," and in this *Annual Report* an excellent beginning was made by reprinting, though somewhat abridged, Sir George Cayley's famous paper on Aerial Navigation, first published in *Nicholson's Journal* in 1809-10. It was not until 1954 that an unabridged copy of the paper was published by the Society.

The same *Annual Report* contained a translation by T. J. Bennett of Alphonse Pénaud's paper on " The Power Developed by Birds," read before the Société Philomatique de Paris that year; also one printed in *L'Aéronaute* on " Law relating to planes gliding in the air." Bennett lived in Oxford most of his life, and not only followed the work of aeronautical pioneers (and translated Mary's and Lucy's papers for the *Annual Reports*) but experimented himself. As late as June 1894 he wrote from Oxford to Lawrence Hargrave in Australia, giving him news of the work of Maxim and Horatio Phillips, adding,

" I also send you photo of my last machine made four or five years ago but not finished. I am now making a modification of your cellular kite with thirty feet of surface. If needful I can make one with 300 feet to carry a man . . . . "

(Continued)

REFERENCES: Brearey—correspondence; *Annual Reports*, 1875-6; *The Times*, 24th December 1876; " Ballooning as a Sport," by B. F. S. Baden Powell, 18; *L'Aéronaute*, 1876.

Graduates' and Students' Section

A Letter from a Reader!

Dear Sir,

May I make a plea for a more lively layout of the Graduates' and Students' Page in our Journal? Many of the articles published on the Page are well worth reading, but I cannot help feeling that the usual expanse of small print must dishearten many potential readers. After all, members are not obliged to read the Page, and there must be many readers who do not manage to struggle through to the announcements of visits and lectures in the bottom right-hand corner. Maybe this is a reason for the poor support some of these events receive!

A few carefully positioned photographs and diagrams could be very effective in breaking up the overall visual monotony of the Page, and bigger headlines might catch the readers' eye before he had a chance to turn to the literary reviews and final advertisements.

Who knows. this might even engender some interest in the Section as a whole!

Southampton. M. V. LOWSON.

Mr. Lowson raises several valid points. We will do our best to liven up the Page as far as our material and format will allow.—HON. ED.

Next Lecture is on 23rd October at 7 p.m.
"Club and Light Aircraft" by D. Ogilvy.
Winter Dance on 24th November 8-11.45 p.m.
Double Tickets 15/- inclusive of refreshments.

Highlights of the Lecture Programme 1961-62

The final details of the Programme of Lectures for the coming Session are now being completed and this is perhaps a good opportunity to present a preview of the good things in store.

An innovation this year is to start the Lectures at 7 p.m. instead of at 7.30 p.m. as in previous years. This is by popular request, but since public opinion has a disconcerting way of changing its mind, the Committee would welcome the views of other Graduates and Students on this. So if you find the time inconvenient, drop a line to the Editor of this Page and suggest a better one.

The first lecture is scheduled for Monday 23rd October and is on "Club and Light Aircraft." The speaker is David Ogilvy, who is probably too well known to need any introduction. Suffice to say that as a director of Derby Aviation and Chief Flying Instructor of Elstree Flying School, his contacts and experience in this field of aviation are quite unrivalled. With the recent upsurge of interest in the executive type of aircraft we hope that this lecture will be one of the outstanding occasions in the year.

The first item in the Programme has been dealt with at some length as it is almost upon us, but mention should be made of some of the other interesting lectures which have been arranged.

On 22nd November we are having a Lecture on Army Aviation, both British and Foreign, by Colonel C. D. S. Kennedy, who is a specialist in this field. The next lecture date is 6th December, when we hope to hear a lecture by an eminent American.

"The New Bluebird" is the exciting title of our January lecture, on the 24th of the month. It will be given by one of the famous Norris Brothers, who are, of course the designers of the Bluebird. Later next year there are lectures on helicopter work in the field and on the selling side of the Aircraft Industry, among others, but more details of those at a later date.

All in all, the Lecture Programme promises to be a most interesting and entertaining one, and we hope it will be well supported. As always, visitors are welcome, so if any friends of yours would like to come, bring them along, whether or not they are members. One last thing, don't forget that coffee and biscuits are served before each lecture.—A.H.F-M.

The organiser of the Section Visit to the Paris Aero Show this year advised the members of the party that he could be recognised at the departure point by his black beard and his name in his lapel. Hence a certain amount of confusion was caused by the arrival of these six gentlemen from Hayes. Order was restored by the appearance of the organiser and a demonstration of his non-detachable beard.

USBORNE MEMORIAL PRIZE

Further to the article on the Society's Prizes and Awards which was published last month, the Hon. Editor welcomes articles eligible for this Prize, with a view to printing them. The Usborne Memorial Prize, you will remember, is awarded for the best contribution to the Society's publications written by a Graduate or Student on some subject of a technical nature connected with aeronautics.

The Hon. Editor's address is:—
P. Hampton, Staff Mess, R.A.E., Farnborough, Hants.

Annual Dance: Friday 24th November

The Winter Dance will be held in the new Lecture Theatre of the Society at 4 Hamilton Place from 8 to 11.45 p.m. to the music of Hugh McCamley.

Double tickets, which include free drink and refreshments in their price of 15/-, are obtainable by post from:
Mr. J. Wilby, 9 Blenheim Avenue, Highfield, Southampton,
or from your local committee member:—

W. G. Wilson, Sales Engineering, de Havilland Aircraft Co. Ltd.
A. H. Frazer-Mitchell, Aero Dept., Handley Page Ltd.
N. R. Craddock, Stress Office, Handley Page Ltd.
J. Wilby, Aero Dept., Southampton University.
P. Hampton, G.W. Dept., R.A.E., Farnborough.
J. D. Brown, Westland Aircraft Ltd. (Fairey Division), Hayes.
R. G. Bustin, Aero Dept., Imperial College.
J. J. White, Vickers-Armstrongs (Aircraft) Ltd., Weybridge.

THE BRANCHES

The Leicester Branch was formed in 1945; its history is a short one, but with the coming of the Beagle there is hope for better times.

IT WAS at Whetstone, near Leicester, that the early experiments with the Jet engine took place, under the leadership of Sir Frank Whittle. The firm formed to carry out this work was known as Power Jets Ltd. and in 1943 members of this organisation, under Dr. H. Roxbee Cox (now Sir Harold) formed the Leicester Branch.

The meetings were held at the Leicester College of Technology, the members from Whetstone being the mainstay of the Branch. A minority part was played by members from Taylorcraft Aeroplanes Ltd. based at Rearsby Aerodrome. The meetings continued until the 1946-1947 session, when Power Jets Ltd. was disbanded and absorbed by the National Gas Turbine Establishment at Pyestock. As all the Branch Officers left at this time, a group from Taylorcraft Aeroplanes Ltd. took over and got the Branch moving again and it continued somewhat unsteadily for several years.

At the Annual General Meeting in 1952, the dwindling of support from members living in or near Leicester was noted; this declining interest arose partially because of the dispersed centres of Aeronautical activity in the area, and in order to widen the field, it was proposed that meetings should be held alternatively in Leicester and at Loughborough College. This arrangement was not entirely successful and by 1956 all meetings were being held at Loughborough. The attendances were mainly from the student body of the College and members of the Staff.

In the meantime, Taylorcraft Aeroplanes Ltd. had changed its name to Auster Aircraft Ltd. and had built up a considerable sized design team, and when a Special General Meeting was called in March 1956 to discuss the proposal: "This Branch shall be closed for lack of support," members of Austers opposed this and made an all-out effort to keep it moving. This was fairly successful and in January 1958 the Branch held its first Main Society lecture—"Aircraft Engines"—given by Mr. A. A. Lombard of Rolls-Royce Ltd. However, following the White Paper on the Aircraft Industry in 1957, extensive redundancies took place at Austers, and later in 1958 the situation became very difficult. It was decided that the Branch should not close down but be allowed to remain in being to await better times.

These turned up at the end of 1960, when Auster Aircraft Ltd. became a member of the Beagle Group under the leadership of Mr. Peter Masefield. It has not been possible as yet to get the Branch moving again but with this resurgence of interest in the Light Aircraft field, the future is more hopeful than could have been expected a few years ago.

It seems that another lecture on "Aircraft Engines" by Rolls-Royce would now be appropriate.

BRANCH NEWS

The new lecture season is now starting, and lecture cards are passing between Branches and the Society, and the dates and occasions will be published in the Diary of the JOURNAL.

In addition to this, it is very pleasing to note the support given to the **Brough** Branch by *The Courier*, the House Journal of Blackburn Aircraft; the Editor always seems to find room for R.Ae.S. activities.

Here is a reduced copy of one of the centre pages, nearly half of which is given to the Branch—or one eighth of *The Courier*.

Since the reduction hardly lends itself to reading, the last paragraph may interest other Branches:—

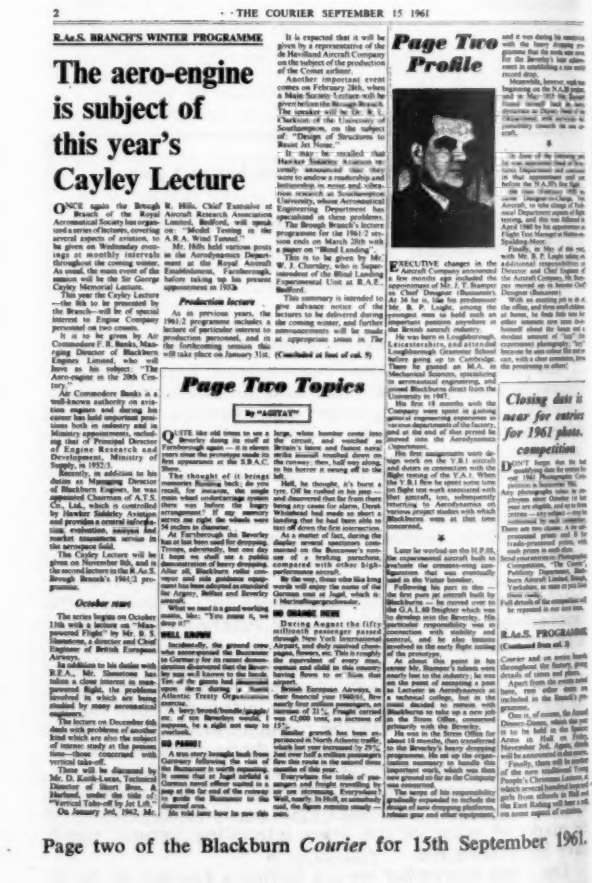
"Finally, there will be another of the now traditional Young People's Christmas Lectures, at which several hundred boys and girls from schools in Hull and the East Riding will hear a talk on some aspect of aviation."

From **Bristol** comes news of their Hon. Secretary, Mr. W. O. Lee, who not only takes on this responsible post, but is also Pilot Officer W. O. Lee, R.A.F., V.R.(T), and a Flight Commander in Bristol.

He has been with his A.T.C. Squadron for some 12 months and is a former navigator with Bomber Command in No. 44 Squadron equipped with Lancasters.

After the war Mr. Lee kept up flying with V.R. Squadrons at Wolverhampton and Filton, and now puts his experience to the good purpose of instruction.

We learn that the Secretary of the **Glasgow** Branch, Mr. W. Newman Alcock has been elected Hon. Associate of the Wingford L.T.A. Society of the U.S.A. as a tribute to his airship researches. He believes he is the only Hon. Associate in the British Commonwealth. Mr. Alcock has worked out a new system of airship propulsion which is causing considerable interest over there.—G.W-W.



2 · THE COURIER SEPTEMBER 15 1961

R.Ae.S. BRANCH'S WINTER PROGRAMME

The aero-engine is subject of this year's Cayley Lecture

ONCE again the Brough Branch of the Royal Aeronautical Society has organised a series of lectures, covering several aspects of aviation, to be given on Wednesday evenings at monthly intervals throughout the coming winter. As usual, the main event of the season will be the Sir George Cayley Memorial Lecture.

This year the Cayley Lecture —the 8th to be presented by the Branch—will be of special interest to Engine Company personnel on two counts.

It is to be given by Air Commodore F. R. Banks, Managing Director of Blackburn Engines Limited, who will have as his subject, "The Aero-engine in the 20th Century."

Air Commodore Banks is a well-known authority on aviation engines and during his career has held important positions both in industry and in Ministry appointments, including that of Principal Director of Engine Research and Development, Ministry of Supply, in 1952/3.

Recently, in addition to his duties as Managing Director of Blackburn Engines, he was appointed Chairman of A.T.S. Co., Ltd., which is controlled by Hawker Siddeley Aviation and provides a central information, evaluation, analysis and market research service in the aerospace field.

The Cayley Lecture will be given on November 8th, and is the second lecture in the R.Ae.S. Brough Branch's 1961/2 programme.

October meet

The series begins on October 11th with a lecture on "Man-powered Flight" by Mr. P. S. Shenstone, a director and Chief Engineer of British European Airways.

In addition to his duties with B.E.A., Mr. Shenstone has taken a close interest in man-powered flight, the problems involved in which are being studied by many aeronautical engineers.

The lecture on December 6th deals with problems of another kind which are also the subject of intense study at the present time—those concerned with vertical take-off.

These will be discussed by Mr. D. Keith-Lucas, Technical Director of Short Bros. & Harland, under the title of "Vertical Take-off by Jet Lift."

R. Hills, Chief Executive of Aircraft Research Association Limited, Bedford, will speak on: "Model Testing, in the A.R.A. Wind Tunnel."

Mr. Hills held various posts in the Aerodynamics Department at the Royal Aircraft Establishment, Farnborough, before taking up his present appointment in 1955.

Production lecture

As in previous years, the 1961/2 programme includes a lecture of particular interest to production personnel, and in the forthcoming session this will take place on January 31st.

It is expected that it will be given by a representative of the de Havilland Aircraft Company on the subject of the production of the Comet airliner.

Another important event comes on February 28th, when a Main Society Lecture will be given before the Brough Branch. The speaker will be Dr. R. L. Harkiss of the University of Southampton, on the subject of "Design of Structures to Resist Jet Noise."

It may be recalled that Hawker Siddeley Aviation recently announced that they were to endow a readership and lectureship in sonic and vibration research at Southampton University, whose Aeronautical Engineering Department has specialised on these problems.

The Brough Branch's lecture programme for the 1961/2 session ends on March 28th with a paper on "Blind Landing."

This is to be given by Mr. W. J. Chorley, who is Superintendent of the Blind Landing Experimental Unit at R.A.E., Bedford.

This summary is intended to give advance notice of the lectures to be delivered during the coming winter, and further announcements will be made at appropriate times in *The Courier*.

(Concluded at foot of col. 9)

Page Two Topics

By "AGITATOR"

QUITE the old times to see a Beverley doing its stuff at the Farnborough again — it is eleven years since the prototype made its first appearance at the S.B.A.C. Show.

The thought of it brings back memories flooding back; do you recall, for instance, the night mists which underlay the airport as there was before the hugely extravagant? If any memory serves me right the wheels were 54 inches in diameter.

At Farnborough the Beverley has often been used for dropping Troops, admittedly, but one day I hope we shall see a public demonstration of heavy dropping. After all, Blackburn roller coverage and sole guidance equipment has been perfected and tested for Argosy, Belfast and Beverley aircraft.

What we need is a good working model

What we need is a good working model, Mr. "Tim" Jones is, we drop it!

WELL KNOWN

Incidentally, the ground crew who accompanied the Beverley to Germany for its recent demonstration display and the Beverley was well known to the locals. Ten of the guests had discovered upon their arrival during a recent Atlantic Ferry Organisation exercise.

A heavy bread/bundle/gaggle etc. of ten Beverleys would, I suppose, be a right nice way to overlook.

NO PANIC!

A recent story brought back from Germany following the visit of the Beverleys is worth repeating. It seems that a Red soldier's German naval officer visited in a jeep at the far end of the runway to greet the Beverleys to the unarmed crew.

He told later how he saw the huge, white bomber come into the circuit, and watched as Britain's latest and fastest naval strike aircraft touched down on the runway; then, half way along, to his horror it swung off to the left.

Half, he thought, it's burnt a tyre. Off he rushed in his jeep — and discovered that the front door being any cause for alarm, Derek Whitehead had made an short a landing that he had been able to taxi off down the first intersection.

As a matter of fact, during the display several spectators commented on the Beverley's non-use of a braking parachute, compared with other high-performance aircraft.

By the way, those who like long words will enjoy the name of the German town at Jagel, which is Hohenlockergrundverkehr.

NO CHANGE HERE

During August the fifty millionth passenger passed through New York International Airport, and duly received champagne, flowers, etc. This is roughly the equivalent of every man, woman and child in this country having flown to or from that airport.

British European Airways, in their financial year ended, for nearly four million passengers, an increase of 21%. Freight carried was 42,000 tons, an increase of 29%.

Similar growth has been experienced in North Atlantic traffic, which last year increased by 29%. Over 1,000,000 passengers flew this route in the second three months of this year.

Everywhere the totals of passengers and freight travelling by air are increasing. Everywhere! Well, nearly. In Hull, as somebody said, the figures remain steady —

Page Two Profile

EXECUTIVE changes in the Aircraft Company announced a few months ago included the appointment of Mr. J. T. Stamper as Chief Designer (Aircraft).

At 34 he is, like his predecessor Mr. B. P. Laight, among the youngest men to hold such an important position anywhere in the British aircraft industry.

He was born in Loughborough, Leicestershire, and after the Loughborough Grammar School before going up to Cambridge. There he gained an M.A. in Mechanical Sciences, specialising in aeronautical engineering, and joined Blackburn direct from the University in 1947.

His first 18 months with the Company were spent in gaining practical engineering experience in various departments of the factory; and at the end of that period he was involved with the Aerodynamics Department.

His first assignments were design work on the Y.B.1 controllable dieters in connection with the flight testing of the Y.A.1. When the Y.B.1 flew he spent some time on flight test work associated with that aircraft, too, subsequently returning to Aerodynamics on various project studies with which Blackburns were at that time concerned.

*

Later he worked on the H.P.01, the experimental aircraft built to evaluate the crossed-wing configuration that was eventually used on the Victor bomber.

Following his part in this — the first years as an aircraft built by Blackburns — he moved over to the G.A.L.60 freighter which was to develop into the Beverley. His particular responsibility was in connection with stability and control, and he also became involved in the early flight testing of the prototype.

At about this point in his career Mr. Bumper's indoors were nearly lost to the industry, he was on the point of accepting a post as Lecturer in Aerodynamics at a technical college, but in the event decided to remain with Blackburns to take up a new job in the Stress Office, commencing particularly with the Beverley.

He was in the Stress Office for about 18 months, then transferred to the Beverley's heavy development programme. He set up the organisation necessary to handle this important work, which was then very ground so far as the Company was concerned.

The scope of his responsibility gradually expanded to include the design of new engineering platforms, release gear and other equipment, and it was during his association with the heavy dropping programme that the work was done for the Beverley's later achievement in establishing a no more record drop.

Meanwhile, however, work on the beginning on the N.A.39 programme, and in May 1955 he was seconded himself back to more conventional duties as Deputy Head of the Aerodynamics Department, and subsequently towards the end of 1956,

*

In June of the following year he was appointed Head of Aerodynamics Department and remained in that appointment until just before the N.A.39's first flight.

He then followed Jeff Quill as Chief Designer (Military Aircraft), to take charge of Technical Department aspects of flight testing, and this was followed in April 1960 by his appointment as Flight Test Manager at Holme-on-Spalding-Moor.

Finally, in May of this year, with Mr. B. P. Laight taking on additional responsibilities as Director and Chief Engineer of the Aircraft Company, Mr. Bumper moved on to become Chief Designer (Aircraft).

With an exacting job to do at the office, and three small children at home, he finds very little or other interests are open to himself about the house and a modest amount of "free" time is expressed pleasingly, "but because he uses colour film and a good eye, with a clear ambition, lots of his processing to others."

Closing date is near for entries for 1961 photo. competition

DON'T forget that the last qualifying date for entries for the 1961 Photographic Competition is September 30th.

Any photographs taken in the photographic year October 1st 1960 are eligible, and up to four entries — any subject — may be submitted by each competitor. There are two classes: A for the professional prints; and B for trade-promotional prints, with cash prizes in each class.

Intra-departmental Photographic Competition, "The Clarke", Publicity Department, Blackburn Aircraft Limited, Brough, Yorkshire, is open to prints of any classes easily.

Full details of the competition will be repeated in our next issue.

R.Ae.S. PROGRAMME

(Continued from col. 2)

Courier and on recent branch programmes throughout the country, giving details of times and place.

Apart from the events noted here, two other items are included in the Branch's programme.

One is, of course, the Annual Dinner-Dance, which this year is to be held in the Space Arena in Hull on Friday, November 3rd. Again, there will be entertainment by the Beverley Players.

Finally, there will be another of the now traditional Young People's Christmas Lectures, at which several hundred boys and girls from schools in Hull and the East Riding will hear a talk on some aspect of aviation.

Page two of the Blackburn *Courier* for 15th September 1961.

THE LIBRARY

Reviews

ENCYCLOPAEDIC DICTIONARY OF PHYSICS. *J. Thewlis (editor-in-chief). Pergamon, Oxford. 1961. 800 pp. Diagrams. £80 per set.*

It is now nearly forty years since the publication of the Dictionary of Physics, edited by Sir Richard Glazebrook, and since then no comparable English work has been attempted until the appearance of the present volumes. During these years the knowledge of physics has been extended enormously and the compilation of a modern dictionary has been rendered far more difficult than it was in Glazebrook's time by the extensive overlapping of physics with other subjects, such as chemistry and astronomy. It must have been exceedingly difficult to decide where to draw the line in selecting material for inclusion in the new dictionary; indeed the Editor-in-Chief says as much in his introduction to the work.

The present brief review is based on an examination of only the first volume (which does not even reach the end of letter C), but it can be fairly safely assumed that this is a sufficient indication of the quality of the whole work. As even this one volume contains 800 large pages, with the text set out in double columns, it is obviously impossible to offer a detailed criticism: the most that can be done is to comment on the general nature of the work. The compilation has involved a great number of writers and helpers and the Editor-in-Chief, Dr. J. Thewlis, with his three Associate Editors, has been aided by as many as 3,000 persons, of whom some 70 are described as Consulting Editors. A list of the names of all contributors is given at the beginning of the volume and it contains many very well-known names, which alone is a guarantee that most of the material has been prepared by experts in the various subjects covered. The articles are arranged in alphabetical order, rather than under general subject headings as in Glazebrook's dictionary; this seems a better arrangement for reference and is claimed to save a good deal of repetition. It means, however, that one must possess the whole series of volumes in order to find anything one may need. In the present days of high costs this is quite a serious matter; not many private individuals are likely to face the price of £80 for the whole work although, doubtless, thousands would like to have it on their shelves.

A very good feature is that nearly every article is subscribed by its author, so that one knows whose views are expressed when opinions, as distinct from facts, are presented. Some of the articles run to more than 2,000 words, from which it can be seen that important matters are located at very considerable length. There are also cross-references to related subjects and in many cases a bibliography of works on the subject under discussion to help those who seek further information.

The general layout of the articles, the printing and binding, and the copious illustrations and diagrams are all excellent and reflect much credit on the publishers. The only criticism one can offer is that the proof-reading seems to have been a little sketchy, as some curious errors have crept in here and there. To mention a few (met quite casually and suggesting that there must be many more), on p. 397 a bracket is missing in equation 23, while on p. 592 a factor of 10^{-8} has been omitted; p. 686 assures us that the differential of tan x is sec x, while on p. 526 occurs the cryptic remark "if no time is not to be lost!" These are not serious mistakes and will generally be easily noticed, but it is a pity that they were not corrected before publication, as an early reprint is not very likely.

It seems quite fair to say that this Dictionary is a very important work and that it should be of great usefulness to many for reference purposes, and also to give those who need it a reasonably full introduction to subjects with which they are not familiar. All those concerned are certainly to be congratulated on the great efforts they must have made to produce such a monumental work.—E. F. RELF.

MODERN FLIGHT DYNAMICS. *W. Richard Kolk. Prentice-Hall International, London. 1961. 288 pp. Diagrams. 50s.*

This book is written "for aeronautical and astronautical engineers—for anyone engaged in the design of aircraft and missiles." The aim is to provide a textbook which deals with the motion and the stability of both aircraft and rockets. The author attempts to do this within the modest compass of 280 pages. Vectors are used freely, but the general mathematical treatment should be well within the grasp of a student of aeronautical engineering.

The first two chapters deal with the derivation of the equations of motion referred to body axes. It seems rather a pity that 40 pages of this short book are devoted to this derivation. Dynamic stability is called, rather misleadingly, a "time-dependent stability."

Only a brief description is given of the aerodynamic derivatives. In this connection, it must be mentioned that the equations of motion have not been given in non-dimensional terms as is the standard practice. The author prefers to treat "all motion as true, where a second is a second and not an inflationary quantity varying with speed, altitude and wing loading." There are distressing changes of notation on pages 45 and 72, which will not help a student. The treatment of sideslip is confused, as is also that of the separability of longitudinal and lateral stability. The stability diagram for longitudinal motion (Fig. 5.5) is not correct, since only the short period mode is taken into account, the phugoid mode being ignored.

In chapter 6, the linearisation of the lateral equations of motion is carried out in a very confusing manner, and one reader was not certain of its validity. A very satisfactory treatment of roll coupling is given in chapter 7.

Chapters 8, 9 and 10, dealing with flying qualities and control systems, are the best chapters in the book. The author is obviously completely at home here, and up-to-date American data are included. The discussion of static stability is, however, very condensed, and the relation between the static margin and the elevator angle to trim is not brought out. The treament of the variation of the stick force with speed (for a mechanical system with no trim tab) is confusing to a beginner and could be omited.

In chapter 11 one case of aeroelastic distortion is considered. This chapter would have been better with more fundamental physical analysis and fewer diagrams of electrical networks. The book is concluded with a chapter on the spinning and tumbling of rockets (treated very simply) and one on celestial mechanics.

As indicated already, the treatment of flying qualities and system analysis is, on the whole, good, but there are other books which give both a far clearer derivation of the fundamental equations and more insight into the aerodynamics.—A. W. BABISTER.

THE MODERN AIRLINER. *Peter W. Brooks. Putnam, London,* 1961. 176 *pp. Illustrated. Index.* 30*s.*

In spite of the fact that during the first decade of air transport and during the initial stages of the turbine-powered air liner era Britain led the world, few serious works on air transport have been written by British authors.

It is therefore extremely satisfying that at last a useful contribution to air transport writing has appeared in Britain by a man closely connected with the business. Peter Brooks, now Fleet Planning Manager of B.E.A., has made a close study of the transport aeroplane, and his book should be required reading for all those in the air transport industry including the manufacture of transport aeroplanes.

Mr. Brooks traces the history of the transport aeroplane showing the most important developments. He provides some very interesting material on early airline operating costs and also gives ample evidence to show why the

United States has established such a firm position and become the world's largest supplier of transport aeroplanes.

On so many occasions when U.S. successes have been discussed, the blame for British failures has been put on Britain's wartime decision not to build transport aircraft and on the support given to U.S. transport designs by military orders.

Mr. Brooks shows that there are other and more valid reasons for U.S. successes, one of the most important being the readiness of U.S. manufacturers to accept new ideas and methods and, if necessary, to abandon their own design features and adopt those of their competitors.

To some extent Mr. Brooks has emphasised progress by comparing aircraft which were typical of their period, using the Fokker F.VIIb/3m, Douglas DC-3, Lockheed L-049, Douglas DC-7C and Boeing 707-420 as examples, a method which has proved highly successful. In addition he includes a considerable volume of information on most of the world's transport aircraft giving main details of size and performance, numbers built and development time scale.

There is a chapter on vertical take-off and landing transports and a most useful bibliography. If any criticism can be levelled at this work it is a regret that there are only a little over 160 pages and that the work is sparsely illustrated. Nevertheless, this book can be regarded as an appetizer because Mr. Brooks has completed a larger work on the same subject and this is to be published later this year.—JOHN STROUD.

DIE BERECHNUNG VON ROTIERENDEN SCHEIBEN UND SCHALEN. *Kurt Löffler. Springer-Verlag, Berlin,* 1961. 241 *pp. Diagrams. DM.*42. *In German.*

For a considerable period, the stressing of mechanical components lagged behind structural stressing, partly because of the greater complexity of shape of machine parts but largely because the little understood conditions of fatigue failure made accurate stressing seem unrewarding. In the past twenty-five years, this has tended to change and more sophisticated stressing methods are being applied to dynamically stressed components. The present work gathers together and extends the information on stress distribution in rotating discs and shells, such as occur in turbines, compressors, impellers and so on.

The general scheme consists essentially in splitting the component into a series of discs and/or ring-shaped circular cylinders and applying appropriate load systems at the junctions of two individual segments, to re-establish compatibility of deflections there.

In the first chapter, the fundamental differential equations are established; chapters 2 and 3 give their solutions for discs of uniform thickness and straight taper. In chapter 4 the method of applying these solutions to discs of arbitrary shape are explained in detail. A tabular method (due to Grammel) and a semi-graphical (Donath-Karas) are presented and compared. For tapered rings, the stress-functions are diagrammatically plotted. Transformation of the differential equations into finite difference equations, for use, *e.g.* in a computer programme, concludes this section.

Chapter 5 deals with the effect of the hub and of flanges, holes and cut-outs in the disc.

In chapter 6 the application of the method of transfer-matrices to all the foregoing cases is shown and this powerful and elegant method is later used in the stressing of shells.

Chapter 7 deals with the "inverse" problem of finding the shape of a disc when the stress distribution is prescribed. The following chapters, 8 to 10, discuss the effects of initial stresses (press-fits or discs shrunk on the shaft), the limiting strength of a disc in the overspeed case, and the stress distribution due to plastic deformations. These items are perhaps not quite so well integrated into the general scheme but appear to be intended as checks after the general stressing has been completed. The next sections deal with the stresses created by applied torque and with the effects of bending stresses; the influences of flanges, radial ribs and cut-outs in the latter case is also considered.

The second part of the book deals with the stressing of shells defined as components having both axial and radial extension, for example, the impellers of centrifugal compressors. The basic method is very similar to that employed for discs, the ring-shaped part-discs being here represented by conical part-shells. Due to the interaction of bending and centrifugal stresses and deflections, the system of differential equations becomes rather complex and fairly radical simplifications are introduced. On the other hand, as the author points out, such components have in the past often been designed by purely empirical methods so that even approximate stressing confers an advantage. The method of calculation rests almost entirely on the use of matrix manipulation and in more complex cases would require the availability of an electronic computor.

This is an excellent piece of work and would well repay translation. Although some may not agree with the author in every respect—for example, in his outspoken preference for radical simplification of geometry and loading in complex cases, rather than the application of more sophisticated mathematical methods—the reviewer has found only one point on which he really disagrees, namely the failure to mention the dangers of stress concentrations. These components, having sudden large changes in cross-section, holes, sharp corners and so on, naturally have regions of high stress concentration, and these are apparent in the stress distributions calculated (although not exact, since the assumptions *e.g.* of uniform distribution across the thickness preclude this). One looks therefore for some comment on the effects of these, but nothing turns up until nearly the end of the book, where the author comments on the fact that a disc or shell with a central hole does not burst in the overspeed case when the stress reaches the failing stress of the material at the point of maximum stress level, but only when the average over the whole section reaches that level. He then states "If a disc had to be designed from that aspect, *i.e.* highest stress peak, one would have to take into account also the stress peaks at all the holes in the disc." One should indeed. Considering the high percentage of such components that fail due to some kind of fatigue cracks, a word of warning might not have been inappropriate.

The book has a bibliography but no index.—E. PRIBRAM.

RUMPF SCHALEN—UND VOLLWAND-BAUWEISE. *Gerd Otto.* Vol. 1. Fuselage. *Freidr. Vieweg, Brunswick,* 1960. 284 *pp. In German. Illustrated. DM* 24.80.

An introduction to the principles of aircraft stressing for junior stressmen entering the German aircraft industry. This, the first volume, contains the basic loading assumptions and simple, *i.e.* engineers' theory, stressing methods for fuselages.—E. PRIBRAM.

DIE DEUTSCHEN FLUGZEUGE 1933-1945. *In German. Karlheinz Kens and Heinz J. Nowarra. Lehmann, Munich.* 1961. 816 *pp. Illustrated.* DM.68.

This is a handsome tome in which the authors have endeavoured to present a comprehensive survey of the development of German aircraft from the rebirth of Germany's aircraft industry in 1933 until the end of the Second World War. Unfortunately, the contents of this book are hardly worthy of its lavish presentation—with its pale blue plastic binding and gold blocking; the authors having done little more than add together in one volume all that has been published on the subject during the past fifteen years, perpetrating innumerable errors and perpetuating those already made in the process. Many of the errors result from carelessness; the majority owe more to the inadequate knowledge of the authors.

Messrs. Kens and Nowarra have evidently drawn their material from any and every source, and they have not been very selective while undertaking this task. A reader with a merely superficial knowledge of the subject matter of the book can detect the most amazing errors in the three-view silhouettes, and typical of the errors of fact which punctuate virtually every section of the book are the identification of the Ar 240V1 as the very different Ar 440V1; the statement

that the Fieseler Fi 333 was merely a project whereas, in fact, three prototypes were built and flown; the inclusion of the so-called "Dornier Do 29" which was as fictional as the so-called Focke-Wulf Fw198! Accuracy cannot be justifiably claimed for this book; neither can completeness, for a number of aircraft actually tested are either mentioned but briefly or omitted completely, such as the Bücker Bü 134 which was built to compete with the Puss Moth. But then the authors appear to have a predilection for projects rather than genuine "hardware."

Virtually as much space is devoted to projected types as to aircraft that actually existed, and in this they have evidently leaned heavily on the contents of A.I.2(G) Report No. 2383. However, many of the so-called "projects" were little more than "paper doodles"; designer's pipe dreams never seriously entertained. Others illustrated had, in fact, been abandoned long before the end of the war, while still more were developed to more advanced stages than those depicted in the pages of this book. The photographs, interspersed with advertisements and many incorrectly captioned, which occupy the last section of the book are, for the most part, of poor quality, some having been heavily retouched while the crossed screens of others reveal the fact that they have been reproduced directly from other publications. The publisher's motto '*Ich habs gewagt*' (I have dared) could hardly be more appropriate than on the title page of this book which is offered in the United Kingdom at the fantastic price of six guineas!—WILLIAM GREEN.

Additions to the Library

Advances in the Astronautical Sciences. Vol 6. (Proceedings of the 6th Annual Meeting at New York City, 18th -21st January 1960). American Astronautical Society. Macmillan, London. 1961. 898 pp. Illustrated. 175s. Fifty-seven research papers given by leading American space scientists, covering communications in space, propulsion, guidance and control, space medicine and astro-biology, space flight mechanics, design of space vehicles, the problems of re-entry of space vehicles, astronautical systems and space physics. No discussions of individual papers, but there is a Panel discussion with the title "Man in Space, When?"

Always Another Dawn. A. Scott Crossfield with Clay Blair Jnr. London Hodder and Stoughton. 1961. 421 pp. Illustrated. 25s. *To be reviewed.*

An Analytical Investigation of Airport Capacity. A. Blumstein. Cornel Aeronautical Laboratory Inc., Buffalo. 1960. 258 pp. N/P. A Ph.D. Thesis, the report examines the problems of air traffic control with emphasis on landing problems.

Angewandte Strömungslehre. Werner Albring. Dresden, Verlag von Theodor Steinkopff. 1961. 380 pp. DM 43. *To be reviewed.*

Development of High-Temperature Strain Gages. U.S. National Bureau of Standards, Washington, U.S.G.P.O. 1961. 20 pp. 1s. 10d. A summary of a research programme to improve high-temperature, electrical resistance strain gauges. Various types of gauge are described.

Magnesium Data Book. Magnesium Elektron Ltd. Magnesium Elektron Ltd. London. 1961. 91 pp. N/P. A neat limp-covered pocket book containing much useful information on specifications and properties of magnesium and its alloys with special reference to the "Elektron" range produced by the firm concerned.

Metallic Fatigue. W. J. Harris. Pergamon Press, London. 1961. 330 pp. Illustrated. 84s. *To be reviewed.*

Noise Abatement Recommendations. International Air Transport Association. I.A.T.A., London. 1961. 4 pp. N/P.

Observer's World Aircraft Directory, The. William Green. Frederick Warne, London. 1961. 354 pp. Illustrated. 15s. *To be reviewed.*

On the Solution of Ill-Conditioned, Simultaneous, Linear, Algebraic Equations by Machine Computation. B. T. Chao and others. University of Illinois Engineering Experimental Station Bulletin No. 459. 1961. 16 pp. 1 dollar.

Proposed Studies on the Implications of Peaceful Space Activities for Human Affairs. Donald N. Michael. U.S.G.P.O., Washington. 1961. 272 pp. 7s. 6d. A Report of the U.S. Committee on Science and Astronautics under nine headings: goals and methods; comments on the organisation and functions of a N.A.S.A. social science research capability; implications of satellite-based communications systems; implications of a space-derived weather predicting system; the implications of technological byproducts; implications for Government operations and personnel use; implications for space industries; general implications for international affairs and foreign policy; attitudes and values.

Radiometric Standards and Measurements. National Physical Laboratory. H.M.S.O., London. 1961. 1s. 9d. No. 23 in the series "Notes on Applied Science." The notes in this case are a description of the methods used at the N.P.L. for the measurement of ultra-violet, visible and infra-red radiation.

Ramjet Technology: Air-Fuel Mixture Preparation. Malcolm A. Weiss. Johns Hopkins University, Maryland. 1961. 130 pp. N/P.

Report of the Committee on the Planning of Helicopter Stations in the London Area. Ministry of Aviation. H.M.S.O., London. 1961. 105 pp. 7s.

Stress Concentration Around Holes. G. N. Savin. Permagon, London. 1961. 430 pp. Diagrams. 84s. *To be reviewed.*

Theory of Elasticity. V. V. Novozhilov. Pergamon Press, London. 1961. 448 pp. £4. *To be reviewed.*

Theory of Non-Homogeneous Anistropic Elastic Shells Subjected to Arbitrary Temperature Distribution. R. E. Miller. University of Illinois Engineering Experimental Station Bulletin 458. 1961. 36 pp. 1 dollar.

Further Papers from the IAS-ARS Meeting June 13th-16th 1961

61-81-1775 The development of a flight test ion engine. J. E. ETTER *et al.*

61-84-1778 Cesium ion beam neutralization in vehicular simulation. J. M. Sellen and R. F. Kemp.

61-85-1779 Surface diffusion studies of cesium on tungsten. H. Shelton.

61-86-1780 Properties of porous tungsten and ionization of cesium. R. A. Hubach and G. D. Seele.

61-98-1792 Dynamics of arc jet system. F. Martinek *et al.*

61-101-1795 Arc jet engine performance—experiment and theory II. R. R. John *et al.*

61-109-1803 X-ray analysis of the lunar surface. D. C. Miller and C. F. Hendee.

61-111-1805 Measurement of properties of the moon from a soft-landed vehicle. M. Eimer.

61-113-1807 From ICBM re-entry to meteorite entry. F. R. Riddell and H. B. Winkler.

61-138-1832 Variation of satellite position with uncertainties in the mean atmospheric density. H. K. Karrenberg *et al.*

61-156-1850 Three-dimensional pulse optimization for vehicles disorbiting from circular orbits. G. E. Fosdick and M. L. Anthony.

61-158-1852 The Mercury animal program. J. P. Henry and J. D. Mosely.

61-160-1854 Measurement of respiration and ventilation in aerospace environment. G. Sullivan *et al.*

61-165-1859 Current congressional legislation affecting aerospace business. A. G. Haley.

61-166-1860 Patents pace the space age. R. R. Lent

61-173-1867 The ionosphere direct measurements satellite instrumentation (Explorer VIII). R. E. Bordeau *et al.*

61-191-1885 Space power trends. D. P. Ross.

61-197-1891 Digilock telemetry system for the Air Force Special Weapons Center's Blue Scout, Jr. R. M. Jaffe.

61-201-1895 Communication with lifting re-entry vehicles. J. H. Goldie.

61-202-1896 Aspects of synchronous communication satellites. N. E. Feldman.

61-203-1897 Some basic response relations for reaction-wheel attitude control. R. H. Cannon.

61-206-1900 Te maneuvers for satelrminallite ascent rendezvous. P. W. Soule and A. T. Kidd.

Reports

AERODYNAMICS

BOUNDARY LAYER

Free-flight skin-temperature and surface-pressure measurements on a highly polished nose having a 100° total-angle cone and a 10° half-angle conical flare section up to a Mach number of 4·08. B. Rashis and A. C. Bond. N.A.S.A. T.N. D-807. April 1961.—(1.1.2.4×1.9.1).

COMPRESSIBLE FLOW

An investigation of transonic flow fields surrounding hot and cold sonic jets. G. Lee. N.A.S.A. D-853.—(1.2.2×1.4).

Some methods of generating cylindrical explosions. R. Collins. U.T.I.A. T.N. 43. *Nov.* 1960.—(1.2.3.2).

FLUID DYNAMICS

Calculation of the radial distribution of the density dependent properties in an axisymmetric gas stream. M. T. Dooley and W. K. McGregor. A.E.D.C.—T.N.-60-216. May 1961.—(1.4.4).

A theoretical investigation of vortex-sheet deformation behind a highly loaded wing and its effect on lift. C. D. Cone. N.A.S.A. T.N. D-657. April 1961.
The induced drag polar is developed for highly loaded wings with elliptical circulation loadings by investigation of the wake deformation process and the properties of the ultimate wake form. Expressions are developed for the rate of deformation of the vortex sheet and for the downstream distance required for complete roll-up.—(1.4.3).

Aerodynamic interaction effects ahead of a sonic jet exhausting perpendicularly from a flat plate into a Mach number 6 free stream. D. J. Romeo and J. R. Sterrett. N.A.S.A. T.N. D-743. April 1961.
Tests were made at an angle of attack of 0° at a Reynolds number per foot of approximately 6×10^6 and with conditions of both transitional and turbulent separation on the flat plate The ratio of jet stagnation pressure to free-stream static pressure was varied from 8 to 460 and the jet slot width from 0·001 to 0·05 in. The ratio of aerodynamic to pure jet reaction force was sizable and varied from 0·5 to 9.—(1.4×1.8.0.1).

A study of laminar compressible viscous pipe flow accelerated by an axial body force, with application to magnetogasdynamics. E. D. Martin. N.A.S.A. T.N. D-855. April 1961.—(1.4.4×1.5.1.1×27.7).

INTERNAL FLOW

Charts for air-flow properties in equilibrium and frozen flows in hypervelocity nozzles. K. K. Yoshikawa and E. D. Katzen. N.A.S.A. T.N. D-693. April 1961.
Air flow properties in nozzles were calculated and charted for equilibrium and frozen air flows. The calculations were made for a range of stagnation pressures up to 10,000 lb./in.^{2} absolute and stagnation enthalpies up to 24,500 Btu per pound. The flow properties charted were temperature, pressure, density, velocity, dynamic pressure, Mach number, Reynolds number, molecular weight fraction, and mass flow.—(1.5.1×1.4×27).

An experimental investigation of the flow in an axisymmetric internal-compression inlet for M=2·75. E. C. Watson and W. P. Peterson. N.A.S.A. T.N. D-784. April 1961.
Detailed pressure measurements were made in the flow field and boundary-layer regions in the supersonic portion of an internal-compression inlet. The axisymmetric inlet had a contraction ratio of 0·48. Tests were conducted at Reynolds number (based on inlet capture diameter) between 3·1 and 4·6 million. Local properties of the flow were determined. From the experimental results, shock-wave patterns and the boundary-layer growth through the inlet were determined.—(1.5.1×27.1.1).

LOADS

Theoretical prediction of the effects of vortex flows on the loading, forces, and moments of slender aircraft. J. R. Spahr. N.A.S.A. T.R. R-101. 1961.
A theoretical method based on slender-body theory is presented for the stepwise calculation of vortex paths in the presence of wing-body combinations and the determination of the load distributions, forces, and moments on the combinations due to the vortices.—(1.6.1×1.8.0.1×1.4.3).

STABILITY AND CONTROL

Aerodynamic and hydrodynamic characteristics of a model of a 500,000-pound high-subsonic multijet logistics transport seaplane. W. J. Kapryan et al. *N.A.S.A. T.N. D-529. April* 1961.
Results are presented for a model of a seaplane designed to conform to the transonic area rule. The aeroplane wing had an aspect ratio of 8·0, taper ratio of 0·30, and 40° sweepback of the quarter-chord line. The wing was twisted and cambered to achieve a high lift-drag ratio. Tests were made to determine the effect of wing transition, nacelles, floats, hull modification, and stabiliser deflection on both the aerodynamic and hydrodynamic characteristics.—(1.8.0.2×1.7×17×3.10).

Static longitudinal and lateral stability characteristics of a right triangular pyramidal lifting reentry configuration at transonic speeds. W. B. Olstad et al. N.A.S.A. T.N. D-655. April 1961.
The model was tested at Mach numbers from 0·60 to 1·19 at angles of attack up to 27·5°. The lower surfaces of the model had a dihedral angle of 45° and the upper surface was flat. Leading-edge sweep was 79·5°. The model was tested with and without a boat-tail afterbody.—(1.8.0.2×25.2).

Subsonic longitudinal aerodynamic characteristics of disks with elliptic cross sections and thickness-diameter ratios from 0·225 to 0·425. F. A. Demele and J. J. Brownson. N.A.S.A. T.N. D-788. April 1961.
An investigation has been made of a family of disc-shaped bodies which might find application in the design of re-entry vehicles Data are presented for angles of attack to 25° over a Mach number range from 0·25 to 0·90 at a Reynolds number of $3·3 \times 10^6$ and over a Reynolds number range from $3·3 \times 10^6$ to 16×10^6 at a Mach number of 0·25.—(1.8.2.2×25.2).

Attitude control requirements for hovering determined through the use of a piloted flight simulator. A. E. Faye. N.A.S.A. T.N. D-792. April 1961.—(1.8.0.1×5.3×5.6).

Design and flight tests of an adaptive control system employing normal-acceleration command. W. E. McNeill et al. *N.A.S.A. T.N. D-858. April* 1961.—(1.8.0.1×13.2).

TESTING AND INSTRUMENTS

A frequency modulation circuit for the measurement of gas conductivity and boundary layer thickness in a shock tube. P. Savic and G. T. Boult. N.R.C. Report M.T.-43. May 1961.—(1.12.6×11).

Note d'information sur la constitution et les possibilités du centre d'essai aérothermodynamiques de Modane-Avrieux. M. Pierre. O.N.E.R.A. N.T. 64. 1961. *(In French.)*—(1.12.1.3).×1.9).

AIRCRAFT

Considerations of methods of improving helicopter efficiency. R. C. Dingeldein. N.A.S.A. T.N. D-734. April 1961.
Recent research results relating to improving the efficiency of a helicopter in hovering and in forward flight are presented.—(3.9×4.4).

AIRCRAFT OPERATION

Airspeed operating practices of turbine-powered commercial transport airplanes. T. L. Coleman et al. *N.A.S.A. T.N. D-744. April* 1961.—(5.3×5.6×3.6).

EXTRA-ATMOSPHERIC TECHNOLOGY

Theory of the secular variations in the orbit of a satellite of an oblate planet. W. A. Mersman. N.A.S.A. T.R. R-99. 1961. (8.2).

An analysis of errors and requirements of an optical guidance technique for approaches to atmospheric entry with interplanetary vehicles. D. P. Harry and A. L. Friedlander. N.A.S.A. T.R. R-102. 1961.—(8.2×26).

Vanguard satellite spin-reduction mechanism. R. C. Baumann. N.A.S.A. T.N. D-496. April 1961.—(8.2).

Vanguard satellite separation mechanisms. R. C. Baumann. N.A.S.A. T.N. D-497. April 1961.—(8.2).

Balancing Vanguard satellites. A. Simkovich and R. C. Baumann. N.A.S.A. T.N. D-498. April 1961.—(8.2).

An analytical approach to the design of an automatic discontinuous control system. L. W. Taylor and J. W. Smith. N.A.S.A. T.N. D-630. April 1961.
The design of an attitude-stabilisation system for a vehicle experiencing negligible external moments is investigated analytically. A discontinuous control system employing a linear switching function and having a neutral zone and time delays is studied and equations are developed to generalise and optimise the system's transient and limit-cycle performance. Example systems which can minimise power required, attitude error, and angular-velocity error within a specified period of operation are included.—(8.2).

Trajectory control in rendezvous problems using proportional navigation. L. S. Cicolani. N.A.S.A. T.N. D-772. April 1961.
The rendezvous problem is defined by the end conditions that the position and velocity of a vehicle and its target are to be matched.—(8.2).

FLIGHT TESTING

A flight study of the dynamic stability of a tilting-rotor convertiplane. H. C. Quigley and D. G. Koenig. N.A.S.A. T.N. D-778. April 1961.—(13.2×3.12).

FUELS AND LUBRICANTS

Transfer of cryogenic fluids by an expulsion-bag technique. P. J. Sirocky. N.A.S.A. T.N. D-849. April 1961.
Tests were run to demonstrate the feasibility of transferring cryogenic fluids by means of an expulsion bag technique.—(14.3×27.3).

MATERIALS

N.A.S.A.—A.E.C. Liquid-Metals Corrosion Meeting. 7th-8th December 1960, *Washington, D.C. Feb.* 1961.
Liquid-metal technology as related to nuclear space power systems is discussed.—(21.2×27.6×34.3.4).

Smooth and sharp-notch tensile properties of cold-reduced A.I.S.I. 301 and 304L stainless-steel sheet at 57°, −320°, and −423°F. M. P. Hanson. N.A.S.A. T.N. D-592. Feb. 1961.—(21.2.1).

A study of the oxidation of materials in an arc-image furnace. R. G. Wilson et al. *N.A.S.A. T.N. D-644. Jan.* 1961.
The rates of weight loss for silicon carbide, graphite, nylon, Bakelite, Fibreglass phenolic, and ammonium chloride have been investigated as a function of oxygen concentration and radiant heat flux.—(21.3).

Effect of surface condition on ductile-to-brittle transition temperature of tungsten. J. R. Stephens. N.A.S.A. T.N. D-676. Feb. 1961.—(21.2.2).

Titanium nitride: an oxidizable coating for the high-temperature protection of graphite. N. T. Wakelyn. N.A.S.A. T.N. D-722. Feb. 1961.—(21.4).

An investigation of high-velocity impact cratering into nonmetallic targets and correlation of penetration data for metallic and nonmetallic targets. W. H. Kinard and R. D. Collins. N.A.S.A. T.N. D-726. Feb. 1961.—(21.3×33.1.2).

The melting points of tantalum carbide and of tungsten. C. F. Zalabak. N.A.S.A. T.N. D-761. March 1961.—(21.3).

Reaction of copper and fluorine from 800° to 1200°F. P. M. O'Donnell and A. E. Spakowski. N.A.S.A. T.N. D-768. April 1961.
To investigate the reaction of gaseous fluorine and copper at high temperatures, corrosion tests were made with thin copper sheets exposed to pure fluorine in an all-glass system.—(21.2.2 ×27.3×32.1).

A sensor for obtaining ablation rates. C. W. Winters and E. M. Bracalente. N.A.S.A. T.N. D-800. April 1961.
A variable-capacitance ablation-rate sensor which allows continuous measurements of ablation rates for Teflon and similar polymers has been developed and tested in an ethylene-heated high-temperature jet at stagnation temperatures ranging from 2,400° to 3,800°F.—(21.3).

A preliminary investigation of the effect of bumpers as a means of reducing projectile penetration. J. O. Funkhouser. N.A.S.A. T.N. D-802. April 1961.—(21.2.2).

Tensile and compressive creep of 6A1-4V titanium-alloy sheet and methods for estimating the minimum creep rate. H. L. Price and G. J. Heimerl. N.A.S.A. T.N. D-805. April 1961.
Results are presented of tensile and compressive creep tests at 800° and 1000°F and of tensile stress-strain tests up to 1200°F.—(21.2.2).

Investigations of grain-boundary stress concentrations in silver chloride. L. E. Goodman. N.A.S.A. T.N. D-832. March 1961.—(21.2.2).

Influence of impurity elements, structure, and prestrain on tensile transition temperature of chromium. B. C. Allen et al. *N.A.S.A. T.N. D-837. April* 1961.
Iodide chromium was fabricated into tensile specimens from as-deposited crystals by arc melting, extrusion, swaging, and grinding. Detailed information is provided on the recrystallisation and grain-growth characteristics of the alloy.—(21.2).

MATHEMATICS

Optimum nonlinear control of a second order nonlinear system. R. Oldenburger et al. *N.A.S.A. T.N. D-825. April* 1961.—(22).

On an improved process in Jacobi's method for finding eigenvalues of a matrix. J. Guest. A.R.L. Note A. 181. *April* 1960.—(22.1).

Fonctions algébriques et fonctions abéliennes. R. Legendre. O.N.E.R.A. Pub. 100. 1961.—(22.1×32.2.1).

MISSILES

A three-dimensional trajectory simulation using six degrees of freedom with arbitrary wind. R. L. James. Appendix B. Damping in pitch and yaw for radial burning solid-propellant rockets. N.A.S.A. T.N. D-641. March 1961.
A rigid airframe with aerodynamic symmetry in roll is treated and the pitch plane is assumed to be a plane of mass symmetry. The missile's position is defined relative to a flat non-rotating earth with constant acceleration of gravity. The equations include the effect of arbitrary wind velocity and azimuth and the aerodynamic coefficients are non-linear with respect to Mach number and flow incidence angle.—(25.1×8.2×1.8.0.1).

Calculation of wind compensation for launching of unguided rockets. R. L. James and R. J. Harris. N.A.S.A. T.N. D-645. April 1961.
A method for calculating wind compensation for unguided missiles is derived which has a greater degree of flexibility than the previously proposed methods. A three-dimensional trajectory simulation with arbitrary wind and non-linear aerodynamic coefficients is used.—(25.1).

An explicit linear filtering solution for the optimization of guidance systems with statistical inputs. E. C. Stewart. N.A.S.A. T.N. D-685. Feb. 1961.—(25.1×22).

Analysis of a four-station doppler tracking method using a simple C.W. beacon. C. L. Fricke and C. W. L. Watkins. N.A.S.A. T.N. D-748. April 1961.—(25×8.2).

Measured response to wind-induced dynamic loads of a full-scale Scout vehicle mounted vertically on a launching tower. G. W. Jones and J. Gilman. N.A.S.A. T.N. D-757. April 1961. (25×33.1.2).

Investigation of the aerodynamic characteristics of two preliminary designs of Scout research vehicle at Mach numbers from 1·77 to 4·65. R. J. Keynton and A. B. Fichter. N.A.S.A. T.N. D-821. April 1961.
The first model was a complete four-stage model and was tested with two nose sections, two interstage flares, and two

sets of trapezoidal fins with tip controls. A second model, consisting of the upper three stages of another design of the Scout research vehicle, was tested with two flares and a cylindrical body extension.—(25×1.8.0.2×8.2).

Tables of rocket functions for zero damping and their connection with Rosser's rocket integrals. J. Guest. A.R.L. Note G.W. 12. *March* 1960.
In the mathematical theory of rocket flight certain functions appear sufficiently often to justify tabulation of the most important integrals at suitable intervals of the argument. This need has been met in this note for zero damping.—(25.2).

NAVIGATION

Piloted simulator tests of a guidance system which can continuously predict landing point of a low L/D vehicle during atmosphere re-entry. R. C. Wingrove and R. E. Coate. N.A.S.A. T.N. D-787. March 1961.—(26×8.2).

POWER PLANTS

Factors that affect operational reliability of turbojet engines. Lewis Center Staff. N.A.S.A. T.R. R-54. 1960.
Failure statistics for this engine are presented, the theory and experimental evidence on how engine failures occur are described, and the methods available for avoiding failure in operation are discussed.—(27.1.1.1×23.1).

Effect of periodic oscillations of velocity and density of a medium on disintegration of liquid jets. I. F. Dityakin and V. I Yagodkin. N.A.S.A. T.T. F-63. April 1961.—(27).

A thermodynamic analysis of thrust augmentation for nuclear rockets. H. M. Henneberry et al. *N.A.S.A. T.N. D-581. March* 1961.
Thrust augmentation of the nuclear rocket system was obtained by the addition of chemical power. A liquid oxidant, oxygen or fluorine, was added to burn with the heated hydrogen propellant issuing from the reactor. The specific impulse of the nuclear rocket afterburner was optimised by the addition of liquid hydrogen along with the oxidant. Data are presented for hydrogen reactor exit temperatures from 3500° to 6500°R.—(27.6×34.4).

Analytical performance characteristics and outlet flow conditions of constant and variable lead helical inducers for cryogenic pumps. J. C. Montgomery. N.A.S.A. T.N. D-583. March 1961.
Simplified radial equilibrium considerations including the radial distribution of loss and deviation angle are used to calculate the performance and outlet flow conditions of constant or variable lead helical inducers for cryogenic pumps.—(27.3.2).

Investigation of the performance of an axial-flow-pump stage designed by the blade-element theory—design and overall performance. J. E. Crouse et al. *N.A.S.A. T.N. D-591. Feb.* 1961.—(27.3).

An optimization of powerplant parameters for orbital-launch nuclear rockets. P. G. Johnson and R. L. Smith. N.A.S.A. T.N. D-675. Feb. 1961.—(27.3×27.6).

Performance of a low-thrust storable-bipropellant rocket at very low chamber pressure. J. P. Wainhainen et al. *N.A.S.A. T.N. D-678. March* 1961.
Characteristic exhaust velocities for the hydrazine and nitrogen tetroxide propellant combination were measured with triplet and two-on-two injectors in a nominal-50-pound-thrust uncooled combustion chamber at a chamber pressure of approximately 10 lb./in.^{2} abs. Steady-state performance is presented for oxidant-fuel mixture ratios from 0·7 to 1·2.—(27.3.1).

Two-dimensional ion beams with small lateral spreading. H. Mirels. N.A.S.A. T.N. D-679. March 1961.—(27.7×8.2).

Theoretical performance of propellants suitable for electrothermal jet engines. J. R. Jack. N.A.S.A. T.N. D-682. March 1961.—(27.7×14×27.3).

Ignition of hydrogen-oxygen rocket combustor with chlorine trifluoride and triethylaluminium. J. W. Gregory and D. M. Straight. N.A.S.A. T.N. D-684. April 1961.
Ignition characteristics of a nominal-125-pound-thrust cold (200° R) gaseous-hydrogen—liquid-oxygen rocket combustor were determined using chlorine trifluoride and triethylaluminium as igniter chemicals. Some design considerations for a simple, reliable chemical ignition system for flight engines are discussed.—(27.3×34.1.1).

Measured two-dimensional damping effectiveness of fuel-sloshing baffle applied to ring baffles in cylindrical tanks. H. A. Cole and B. J. Gambucci. N.A.S.A. T.N. D-694. Feb. 1961.
Measured two-dimensional damping forces of baffles with various shapes and perforations are presented for fluid conditions representative of those in liquid-fuel rocket vehicles. Application of the results in the prediction of damping effectiveness of ring baffles in cylindrical tanks is demonstrated.—(27.3×33.1.2×17.1).

An experimental study of continuous plasma flows driven by a confined arc in a transverse magnetic field. R. L. Barger et al. *N.A.S.A. T.N. D-716. March* 1961.
A crossed-field, continuous-flow plasma accelerator has been built and successfully operated. Some of the problems discussed are ion slip, stability and uniformity of the discharge, effect of the magnetic field on electron emission, use of preionisation, and electrode contamination.—(27.7×32.2.5×1.4.4).

The effect on thrust minus base drag of exchanging base area for nozzle expansion in supersonic nozzles at transonic Mach numbers. T. H. Slocumb and E. H. Andrews. N.A.S.A. T.N. D-754. April 1961.
A wind-tunnel investigation to determine the effect on thrust minus base drag of exchanging base area for nozzle overexpansion on a cylindrical afterbody with a single supersonic nozzle has been conducted at Mach numbers from 0·9 to 1·4. The throat-to-base diameter ratio has been varied from 0·320 to 0·550; the jet-to-base diameter ratio from 0·320 to 1, resulting in a jet Mach number variation of 1·0 to 3·897. The jet total-pressure ration ranged from 2 to approximately 22.—(27).

Examination of pressure oscillations induced by changes in the burning rate of flames. R. L. Schalla. N.A.S.A. T.N. D-764. April 1961.
Variations in frequency and amplitude of pressure oscillations created by vertical propagation across composition gradients were investigated in one-inch-square flame tubes.—(27.3×32.1).

Performance evaluation of a two-dimensional ion rocket using through-feed and porous tungsten ionizers. D. L. Lockwood and R. J. Cybulski. N.A.S.A. T.N. D-766. April 1961.—(27.7×8.2×11).

A wind-tunnel investigation of a 4-foot-diameter ducted fan mounted on the tip of a semispan wing. P. F. Yaggy and K. W. Mort. N.A.S.A. T.N. D-776. March 1961.
Variations of duct angle, power required, and pitching moment were obtained for force-balanced conditions simulating level, unaccelerated, transition flight from 0 to 140 knots. The investigation included tests to determine the effectiveness of movable vanes in the duct.—(27×1.10.2.2×1.8.2.2).

Aerodynamics of a tilting ducted fan configuration. P. F. Yaggy and K. W. Goodson. N.A.S.A. T.N. D-785. March 1961.
Tests of a 4-foot diameter ducted fan mounted on the tip of a semi-span wing. The effects of the tilting ducted fan on aeroplane longitudinal trim and control are examined over a speed range corresponding to transition from hover to aeroplane flight. A brief evaluation of lateral control by differential thrust of the ducted fan is included.—(27×1.10.2.2×1.8.2.2×1.8.1.2).

Film condensation with and without body force in boundary-layer flow of vapor over a flat plate. P. M. Chung. N.A.S.A. T.N. D-790. April 1961.
Laminar film condensation under the simultaneous influence of gas-liquid interface shear and body force (g force) is analysed over a flat plate. Important parameters governing condensation and heat transfer of pure vapour are determined. Mixtures of condensable vapour and non-condensable gas are also analysed. The conditions under which the body force has a significant influence on condensation are determined.—(27.3×32.1).

PROPELLERS

An analytical treatment of aircraft propeller precession instability. W. H. Reed and S. R. Bland. N.A.S.A. T.N. D-659. Jan. 1961.—(29.6).

FATIGUE

The fatigue strength characteristics of a single spar wing. W. J. Winkworth. C.P. 535. 1961.
Full scale fatigue tests on the wings of the Vickers Varsity aircraft, in which the conditions of atmospheric turbulence and the transition from ground to air were represented in the fatigue loading programme. Major failures from fatigue occurred in the spar tension boom in both the inner and outer portions of the wing. The test results illustrate the fatigue behaviour of single spar wing structures.—(31.2.4.2×3.6).

Fatigue-crack propagation in aluminum-alloy tension panels. R. E. Whaley and P. R. Kurzhals. N.A.S.A. T.N. D-543. Nov. 1960.
Results are presented of a series of fatigue tests to study crack propagation and the resulting stress distributions in tension panels.—(31.2.2.3.2.1.6×31.2.3.3.3×21.2.2).

Fatigue investigation of full-scale wing panels of 7075 *aluminum alloy. C. B. Castle and J. F. Ward. N.A.S.A. T.N. D-635. April* 1961.
Results of a fatigue investigation conducted using 18 outer wing panels of T-29A aeroplanes. Constant-amplitude tests were performed by using the resonant-frequency method at three different alternating load levels superposed on a 1*g*, or level-flight mean load. Information is presented on crack location, cycles to crack initiation, crack propagation, and residual static strength.—(31.2.4.2×21.2.2).

Experimental investigation of effects of random loading on the fatigue life of notched cantilever-beam specimens of S.A.E. 4130 *normalized steel. R. W. Fralich. N.A.S.A. T.N. D-663. Feb.* 1961.
Fatigue results for both constant-amplitude and random loading. The fatigue lives for these two sets of results are compared at equal root-mean-square values of peak stresses. A comparison of the random-loading results is also made with theoretical results based on the commonly used assumption of linear cumulative fatigue damage.—(31.2.2×21.2.1).

Factors in evaluating fatigue life of structural parts. W. Illg. N.A.S.A. T.N. D-725. April 1961.
Three facets of fatigue testing are discussed; variable-amplitude loading, fatigue-crack propagation, and equivalent fatigue loading. Experimental test results are included to support conclusions.—(31.2.1).

Systematic axial load fatigue tests using unnotched aluminum alloy 2024-*T4 extruded bar specimens. S. R. Swanson. U.T.I.A. T.N.* 35. *May* 1960.
Results are presented of a series of axial-load fatigue tests performed on aluminium alloy 2024-T4 extruded bar The basic single-level *S-N* relation was established using nine specimens at each of fifteen alternating stress amplitudes. An analytical relation was found to fit the observed damage behaviour at high stress levels (over 0·1 per cent Proof Stress).—(31.1×31.2.2.3.2.1).

The materials fatigue problem in Australia. W. W. Johnstone and J. Y. Mann. A.R.L. Report S.M. 278. *Sept.* 1960.—(31.2.2.1).

SCIENCE—GENERAL

Geophysical research with the aid of rockets and artificial satellites. A. A. Blagonravov and M. G. Kroshkin. N.A.S.A. T.T. F-57. Feb. 1961.—(32.2×8.1).

Communication concerning scientific works in the field of geomagnetism and aeronomy during 1957-1959. *N.A.S.A. T.T. F-60. March* 1961.—(32.2×32.1).

Irradiation effects of 22 *and* 240 *Mev protons on several transistors and solar cells. W. C. Hulten* et al. *N.A.S.A. T.N. D-718. April* 1961.
This report covers proton bombardment effects on electronic components as determined from simulation of two portions of the proton spectrum to be encountered in the earth's trapped radiation belts.—(32.2.5×11).

On the induced flow of an electrically conducting liquid in a rectangular duct by electric and magnetic fields of finite extent. V. J. Rossow et al. *N.A.S.A. T.N. D-347. Jan.* 1961.
Results of an investigation on a direct-current electromagnetic pump that moves a stream of copper sulphate solution through a clear plastic channel.—(32.2.1).

Angular motion of the spin axis of the Tiros 1 *meteorological satellite due to magnetic and gravitational torques. W. R. Bandeen and W. P. Manger. N.A.S.A. T.N. D-571. April* 1961.—(32.2×8.2).

Analysis of gravitational and geometric aspects of geodetic utilization of satellites. W. M. Kaula. N.A.S.A. T.N. D-572. March 1961.—(32.2×8.2).

A reference atmosphere for Patrick A.F.B., Florida (Annual)—O. E. Smith. N.A.S.A. T.N. D-595. March 1961.—(32.2×24×25.4).

Measurement of upper-atmosphere structure by means of the pitot-static tube. J. E. Ainsworth et al. *N.A.S.A. T.N. D-670. Feb.* 1961.
Profiles of atmospheric pressure, density, and temperature for the region 20 to 110 km above Fort Churchill, Canada, were computed from the data obtained during a single fall-day flight. The instrumentation, method of measurement, and results are discussed. Methods are prescribed for using the Pitot-static tube for accurate synoptic measurements of atmospheric structure from 20 to 80 km and for measuring possible semi-diurnal pressure variations in the same region.—(32.2×24).

Thermoluminescence of sodium chloride irradiated with 40-*Mev alpha particles. C. C. Giamati* et al. *N.A.S.A. T.N. D-683. March* 1961.—(32.2.5).

*The Ionosphere Beacon Satellite, S-*45. *M. J. Aucremanne. N.A.S.A. T.N. D-695. Jan.* 1961.
Intended primarily for experimenters in ionospheric research. Experiments proposed by the four major contractors to N.A.S.A. in connection with the Ionosphere Beacon Satellite are described. Sufficient description of the satellite is presented so that experimenters may use the Beacon Satellite to conduct their own studies of the ionosphere.—(32.2×8.2).

Broad-band ultraviolet filters. C. B. Childs. N.A.S.A. T.N. D-697. April 1961.—(32.2.4).

An absolute definition of phase shift in the elastic scattering of a particle from compound systems. A. Temkin. N.A.S.A. T.N. D-698. April 1961.—(32.2).

Preliminary study of prediction aspects of solar cosmic ray events. K. A. Anderson. N.A.S.A. T.N. D-700. April 1961.—(32.2.5×8.1).

Seasonal, latitudinal and diurnal variations in the upper atmosphere. W. Nordberg and W. G. Stroud. N.A.S.A. T.N. D-703. April 1961.—(32.2×8.2).

Ionization and deionization processes in low-density plasma flows. R. L. Barger. N.A.S.A. T.N. D-740. April 1961.
Some of the topics analysed and discussed are: the relative importance of the various recombination mechanisms, catalytic deionization by electronegative particles, delayed ionization produced by metastable action, and heating of the flow by deionization reactions.—(32.2.5×1.4.4×27.7).

Reflection of elastic waves from the wavy boundary of a half-space. J. W. Dunkin and A. C. Eringen. Purdue Univ. A. & E.Sc. T.R. 17. *October.*—(32.2.3×33.1.2).

On the propagation of waves in an electromagnetic elastic solid. J. W. Dunkin and A. C. Eringen. Purdue Univ. A. & E.Sc. T.R. 18. *May* 1961.—(32.2.1×32.2.3×33.1.2).

Measurement of rotational temperature, vibrational temperature, and molecule concentration, in non-radiating flows of low density nitrogen. E. P. Muntz. U.T.I.A. Report 71. *April* 1961.—(32.2×1.4).

*Application of the logarithmic electrolytic tank to servo-mechanism design. T. J. Struys. A.R.L. Report I.*23. *April* 1960.
The method is particularly convenient for obtaining the phase angle loci required in the design of certain types of servo-mechanisms. Application of the tank to solving polynomial equations with complex coefficients is discussed.—(32.2.1×22.1×23.3).

STRUCTURES

LOADS

Atmospheric turbulence encountered over the Atlantic by stratocruiser aircraft. J. E. Aplin. C.P. 533. 1961.—(33.1.1×24).

The effect of the behavior of the load on the frequency of the free vibrations of a ring. E. B. Wasserman. N.A.S.A. T.T. F-52. Jan. 1961.
The problem of vibrations of radially loaded flexible circular rings is investigated. Expressions are obtained for the frequencies and critical loads. Examples of rings with circular, tubular, square, and rectangular cross sections are given.—(33.1.2).

A design study of the inflated sphere landing vehicle, including the landing performance and the effects of deviation from design conditions. E. D. Martin. N.A.S.A. T.N. D-692. April 1961.—(33.1×33.2.3.0).

Structural-loads surveys on two tilt-wing V.T.O.L. configurations. J. F. Ward. N.A.S.A. T.N. D-729. March 1961.
The first loads programme discussed concerns the airframe vibratory loads encountered during flight tests of the VZ-2 tilt-wing VTOL aircraft throughout the operational range from hover to cruise flight. The primary sources of airframe vibration were wing-stall buffeting and tail buffeting in descents. The second programme concerns the initial results of a structural-loads survey conducted as part of the wind-tunnel test of a large-scale tilt-wing research model. This loads programme deals with the steady wing loads measured throughout simulated transition from hover to cruise.—(33.1.1×33.1.2×3.12).

The damping of aluminium honeycomb sandwich beams. D. J. Mead and G. R. Froud. U.S.A.A. Report 144. *July* 1960.—(33.1.2×21.2.3).

An experimental investigation of the damping properties of Aquaplas under random and harmonic excitation. D. J. Mead and A. J. Preplove. A.A.S.U. Report 173. *June* 1961.—(33.1.2).

Contribution a l'étude des caractéristiques vibratoires non linéaires d'une éprouvette en matériau plastique. C. Herve. Pubs. Sc. et Tech. N.T. 95. 1961. (*In French.*)—(33.1.2).

THEORY AND ANALYSIS

The control surface supported by means of a continuous hinge. E. Kosko. N.R.C. Report L.R.-303. *March* 1961.
An elastic analysis is made of the loads transmitted between a movable control surface and a fixed supporting structure. Explicit expressions and numerical results are given, with estimates for the concentrated reactions at the ends of the hinge.—(33.2.3.4×33.2.4.13×1.3).

Beating the heat barrier. J. Taylor. C.P. 545. 1961.
A short survey of the characteristics of aerodynamic heating at supersonic speeds and of the properties of a typical aluminium alloy when exposed to increased temperatures for prolonged periods. With this information as a datum an estimate is made of the minimum combined weight of cooling and insulation required for an aluminium aircraft structure; the study extends to $M=10$, height of 250,000 ft. and range of 5000 miles.—(33.2.4.0.9×21.2.2×1.9.1).

Flight investigation of effects of selected operating conditions on the bending and torsional moments encountered by a helicopter rotor blade. L. H. Ludi. N.A.S.A. T.N. D-759. April 1961.—(33.2.4.1.2×33.2.4.1.5×3.9×4.4.1).

Residual static strength of aluminum-alloy box beams containing fatigue cracks in the tension covers. H. A. Leybold. N.A.S.A. T.N. D-796. April 1961.
The beams were constructed of 7075 and 2024 aluminium alloy according to several designs and employed stringers that were either bonded, riveted, or an integral part of the skin.—(33.2.4.1×21.2.2×31.2.2.3.2.1.4).

Optimum design of a band reinforced pressurised cylinder. D. S. Houghton. C.o.A. Note 116. *April* 1961.
The surface stresses in band reinforced cylindrical pressure vessels are examined, and an equivalent stress determined by using the Mises-Hencky criterion. By comparing the equivalent stress to the band stress, the efficiency of the structural material can be established, and by equating these stresses to their respective yield stresses, the theoretical maximum strength of the structure can be found. Once the material properties of the shell and the reinforcing bands have been specified, the optimum structural layout can be determined.—(33.2.4.3.7).

Stresses around some unreinforced cutouts under various loading conditions. D. S. Houghton and A. Rothwell. C.o.A. Report 146. *March* 1961.
A number of experimental results are given for unreinforced circular, elliptical and square cut-outs with rounded corners, under a variety of loading conditions. Results are then compared with the infinite flat plate solution, using the complex stress function and the method of conformal transformation.—(33.2.4.5.0).

Theoretical elastic stress distributions arising from discontinuities and edge loads in several shell-type structures. R. H. Johns and T. W. Orange. N.A.S.A. T.R. R-103. 1961.—(33.2.4.3×33.2.4.11).

Collision integrals for a modified Stockmayer potential. E. C. Itean et al. *N.A.S.A. T.N. D*-481. *Jan.* 1961.—(33.2.5).

Optimum design of insulated compression plates subjected to aerodynamic heating. J. R. Davidson and J. F. Dalby. N.A.S.A. T.N. D-520. *Jan.* 1961.
Charts have been prepared for four materials.—(33.2.4.5.9×21.2).

Local buckling of longitudinally stiffened curves plates. I. P. Peterson and R. O. Whitley. N.A.S.A. T.N. D-750. *April* 1961.
Design information is presented on the buckling strength of longitudinally stiffened curved plates. Design charts for determining the buckling strength of flat plates stiffened longitudinally by *Z*-section stringers are given for plate and stiffener proportions representative of stiffened curved plates, and a semi-empirical procedure is suggested from which the effect of curvature on the buckling strength of the plate can be determined.—(33.2.4.9.1).

General theory of large deflections of thin shells. E. H. Dill. N.A.S.A. T.N. D-826. *March* 1961.—(33.2.4.11).

Thermal stresses in multi-layer spherical shells. G. R. Cowper. N.R.C. Report L.R-300. *Feb.* 1961.
The method of stress calculation is outlined and numerical results presented for aluminium shells covered by layers of various insulating materials.—(33.2.4.11.9×21.2.2).

The effect of axial constraint on the instability of thin conical shells under external pressure. J. Singer. Israel Inst. Tech. Haifa, Report 13. *December* 1960.
The effect of axial elastic restrain, is analysed by a Rayleigh Ritz approach. For the case of hydrostatic pressure, the effect is calculated for a wide range of parameters and design curves are presented for the percentage increase in critical pressure.—(33.2.4.3.7).

TESTING

A note on test factors. N. I. Bullen. R. & M. 3166. 1961.
The calculation of test factors is reviewed. The distribution of the population from which the test sample is taken is assumed to be Gaussian. Three cases are discussed, in which (1) there is no prior knowledge of the mean or standard deviation; (2) there is no prior knowledge of the mean but the standard deviation is a given fraction of the mean (*i.e.* coefficient of variation known); (3) there is no prior knowledge of the mean but the standard deviation is known.—(33.3.2).

THERMODYNAMICS

Hot-wire calorimetry: theory and applications to ion rocket research. L. V. Baldwin and V. A. Sandborn. N.A.S.A. T.R. R-98. 1961.—(34.2.2×27.3×32.2.2×1.12.6.3).

An analysis of thermal radiation heat transfer in a nuclear-rocket nozzle. W. H. Robbins. N.A.S.A. T.N. D-586. *Jan.* 1961.
A calculation procedure was developed for determining the radiant heat flux along a nuclear-rocket nozzle wall.—(34.3.1×27.6).

Analysis of effective thermal conductivities of honeycomb-core and corrugated-core sandwich panels. R. T. Swann and C. M. Pittman. N.A.S.A. T.N. D-714. *April* 1961.
Equations are derived for the transfer of heat in sandwich panels. Temperature distributions and effective thermal conductivities are calculated for both honeycomb-core and corrugated-core sandwich panels. Equations are derived which give the effective thermal conductivities as functions of the geometric parameters and material properties.—(34.3.3×21.2.3×21.3.6).